Remembering to remember: how do children develop the skills necessary to organise their future behaviour?

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To Jean and Alan Mackinlay

For setting the best example I could wish to follow
Abstract

The successful organisation of future behaviour is a fundamental skill underpinning daily life. Each day we plan to perform multiple actions and activities ahead of time, and execute these planned actions at an appropriate time and place. The cognitive processes underlying such 'future-oriented' skills have been the recent focus of adult studies; surprisingly little research has investigated the development of these abilities in children. Adult research studies have successfully employed 'multitasking paradigms' to study these skills and have identified a number of cognitive processes that support the organisation of future behaviour. The focus of this research was to use multitasking as a methodology to assess the cognitive skills involved in organisation of future behaviour in childhood.

We developed the Battersea Multitask Paradigm, a novel test to assess future organisation skills in children and adults. The paradigm also enabled us to investigate the cognitive processes that underlie the organisation of future action, including retrospective memory, prospective memory (memory for intentions), planning and executive functions. We tested groups of children aged 6, 8, 10, 12 and 14 years, and a group of young adults, and found significant developmental differences in multitask performance. These findings are interpreted as evidence that the ability to organise future behaviour develops from 6 years of age into young adulthood. We also examined the developmental trajectories of the cognitive processes underlying multitasking. Results indicate that children under 10 years old find it difficult to co-ordinate performance across multiple tasks, and their performance declines when they are asked to do so. This is likely to represent age-related differences in prospective memory and information processing capacity. In contrast, performance differences between older children and adults are attributable to developments in executive strategy use.

The ability to organise future behaviour can be impaired in children with developmental disorders. We investigated multitasking in a group of boys with autism spectrum disorder. These boys had significant difficulties organising future activities in their day-to-day lives, and this was reflected in multitask performance decrements relative to typically developing controls. The Battersea Multitask Paradigm is a novel test with the unusual quality of being useable and challenging to 6 year olds as well as to adults and atypical populations, which can reveal the component parts of the cognitive processes underlying the organisation of future-oriented behaviour.
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Burns’ musings upon turning up a field mouse over 200 years ago reflect an issue that is still of immense scientific interest today. The fact that we are able to command our thoughts both backwards and forwards in time is, arguably, a uniquely human attribute (Suddendorf & Corballis, 1997; Tomasello & Call, 1997; Tulving, 2001). Whilst other species can undoubtedly ‘learn’ from past experiences to guide present actions, only humans reflect on past experiences to guide future behaviour (Donald, 1991). In addition, humans can plan future actions in novel situations, in the absence of any relevant past experience. A high profile example of this would be the space missions undertaken over past decades.
Marshall Haith and colleagues eloquently sum the importance of future behaviour to our everyday lives:

“Our society is obsessed with the future... Corporations devote a great deal of energy to developing strategic plans, missions and goal statements, and implementation strategies for ensuring competitive positioning. All of these institutional efforts reflect a strong orientation to the future. A consideration of the psychological world of the individual reveals little difference. We are constantly thinking through such issues as what to wear today, whom we should invite for lunch, how best to organize a presentation, and which investment strategy will yield the best return for retirement.” (Haith, Benson, Roberts & Pennington; 1994: page 1)

Despite this clear indication that we spend great deal of time and expend a considerable amount of effort engaging in activities oriented towards the future, it is only recently that psychological research has turned its attention to investigating the sorts of processes which may underlie these abilities. This is in stark contrast to what amounts to over a century of research into ‘past-oriented’ processes, or memory (Kliegel & Martin, 2003). Current evidence indicates that a number of cognitive processes support future-oriented behaviours, including executive functions, retrospective mnemonic processes and prospective mnemonic processes (Burgess, Veitch, Costello & Shallice, 2000).

The central question of this thesis concerns how children develop the skills necessary to organise their future behaviour. As children mature they grow increasingly able to organise their future actions; remembering to bring letters or lunchboxes home from school; organising homework time around seeing friends and watching favourite TV shows; changing perspectives on what they would like to be when they ‘grow up.’ Research into the development of these abilities in children is not non-existent, but it is fragmented (Haith et al., 1994). It is due to this relative paucity of research into future-oriented processes in children, that this thesis begins with a review of relevant adult research.
Chapter 2: The organisation of future behaviour in adults

The organisation of 'future behaviour' in adults

The organisation of future behaviour has received a lot of research interest in recent times, chiefly from adult neuropsychology, where studies of frontal lobe patients in whom the capacity to organise their day-to-day activities appears to be selectively impaired (Shallice & Burgess, 1991); and from the growing body of research into 'prospective memory' the key psychological process thought to support the prospective organisation of behaviour. Specifically, the past few years have seen the convergence of these two fields, with the generation of new theories about the psychological processes and neural mechanisms that mediate prospective organisational skills. This coupled with the fact that these skills are central and essential to our everyday functioning (e.g. Burgess, 2000; Haith, 1994) means that this is an exciting time to be investigating the organisation of future behaviour. It is now clear that many processes contribute to the organisation of future behaviour. Of these prospective memory (PM) is the key process, although retrospective memory and executive functions also fulfil an important role. In the section that follows, each of these processes is reviewed in turn, alongside evidence indicating the unique relationships between them as they support the organisation of future behaviour.
2.1 Adult neuropsychological research

Evidence from neuropsychological studies has contributed a great deal to research into the organisation of future behaviour. Adult patients with frontal lobe damage may exhibit a selective deficit in the ability to organise future actions. Paradigms to test this ability have been designed on the basis of evidence from these patients and a model of the organisation of future action has been developed by neuropsychologists. In this section each of these contributions is considered.

2.1.1 Adult frontal lobe patients

Research on adult patients with frontal lobe damage has highlighted patients who may display a selective deficit in their ability to organise their future behaviour. These patients exhibit relatively spared performance on traditional measures of intellectual functioning and many tests of executive functioning, in contrast to a striking inability to organise their behaviour in everyday life (e.g., Shallice & Burgess, 1991; Bechara, Tranel & Damasio, 2000). Bechara and colleagues describe these patients as seeming to have a ‘myopia’ for the future, being: “...oblivious to the consequences of their actions...guided only by immediate prospects... [whilst] in contrast to this impairment in real-life decision making, most of these patients retain normal intellect, memory and problem-solving ability within laboratory settings...” (Bechara, Tranel & Damasio, 2000: 2189). Shallice and Burgess (1991) have termed this particular pattern of difficulties ‘strategy application disorder.’ Consider Shallice and Burgess’ description of patient FS, a 55-year-old woman who had previously sustained two head injuries and had an extensive lesion in her left frontal lobe:

“F.S....undertakes virtually no inessential or novel activities...She seldom goes out in the evening, and virtually never travels away from her home town. Others always make arrangements when any joint activity is to be carried out. She is said by her sister never to organise anything. She shops every day buying only a few things on any occasion and never visits supermarkets. She had no activity planned for the following weekend and could give no example where anyone had relied on her to do anything...” (Shallice & Burgess, 1991: 730).

This description of FS illustrates just how debilitating a deficit in the ability to organise future activities can be. Social relationships may be affected as people interpret a lack of follow through in social engagements as a lack of interest. Self-esteem many suffer as individuals increasingly feel that others
cannot rely upon them, or that they cannot rely upon themselves. Even basic everyday tasks such as going to the supermarket present great difficulty, as buying multiple items at one time proves too much to organise and remember. In contrast to her impaired ability to prospectively organise activities in her everyday life, FS performed well on a number of traditional neuropsychological tests. Her IQ was in the average/high average range (verbal IQ = 135 and performance IQ = 114), and she had no language or perceptual difficulties. She performed well some tests traditionally sensitive to frontal lobe functioning including the Stroop test of inhibitory control (Stroop, 1935), the Tower of London test of planning ability (Shallice, 1982) and the Wisconsin Card Sort Test (WCST) which measures cognitive flexibility (Nelson, 1976). However, FS demonstrated impaired performance on a few other tests of frontal lobe functioning, including the Trails Test part B which also measures cognitive flexibility (Reitan, 1958). Finally, FS' performance on memory tests was more variable, but her memory difficulties were considered secondary to her frontal/organisational deficits (Shallice & Burgess, 1991).

A number of patients with this seemingly 'selective' deficit in the everyday organisation of future behaviour have been reported in the literature (Esiinger & Damasio, 1985; Duncan, Burgess & Emslie, 1995; Fortin, Godbout & Braun, 2002; Goldstein, Bernard, Fenwick et al., 1993; c.f. Burgess, 1997 for a review). An alternative description of these patients' difficulties is 'goal neglect' (Duncan, 1986; Duncan et al., 1995; Duncan, Emslie, Williams et al., 1996). All these patients have relatively preserved performance on traditional neuropsychological tests in the face of a grossly impaired ability to manage their day-to-day lives. This seemingly contradictory finding was attributed to the fact that the traditional test environment is typically highly structured with clearly defined task goals (Shallice & Burgess, 1991). In this environment, patients can identify the goal in question and focus all their efforts towards achieving it. In contrast, organising activities in real life takes place in a more fluid, less tightly regulated environment. In order to test this hypothesis, Shallice & Burgess (1991) designed two tasks aimed at capturing the relatively unstructured nature of goal-directed problem-solving in everyday life. These tasks require the individual to work towards multiple sub-goals rather than a single overall goal. Originally called 'multiple sub-goal scheduling' tasks, they are now more commonly termed 'multitasking' tests (Burgess et al., 2000);
2.1.2 Multitasking tests

The Multiple Errands Test (MET) was designed as a 'real life' multitask test in which patients were required to complete a number of errands in a small London shopping precinct. The errands varied in their complexity, from simple ‘item-buying’ tasks to a more complex ‘information-gathering’ task. Performance was constrained by a set of rules such as ‘you must not enter a shop other than to buy something.’ Compared to matched controls, patients with frontal lobe damage made more errors and failed to accomplish as many errands, were significantly more inefficient at performing the errands they did attempt and frequently broke/ attempted to circumvent the rules (e.g. entering into arguments with shopkeepers caused by asking to have items for free). In an effort to transfer these performance traits to a more manageable setting than a shopping complex, Shallice and Burgess (1991) devised a laboratory based equivalent of the MET, the Six Elements Test (SET). In this test participants were presented with six tasks governed by a set of rules, and told that they had 15 minutes in which to attempt some of each task. The goal was to obtain as many points as possible during this time without breaking any rules. Once again, the frontal lobe patients failed to perform the task as efficiently as controls. None of these patients successfully performed all six subtasks; they typically spent unusually short or long periods of time on the subtasks they did attempt, broke the rules and carried out subtasks incorrectly.

Since these early tests, a number of paradigms have been designed which successfully capture the frequent rule-breaking behaviours and cognitive inflexibility demonstrated by frontal lobe patients when organising future oriented activities in everyday life (e.g., Burgess, Alderman, Evans, Emslie & Wilson, 1998; Burgess & Shallice, 1996 a, b; Burgess, Veitch, Costello & Shallice, 2000; Shallice & Burgess, 1991; Wilson, Evans, Emslie, Alderman & Burgess, 1998). These multitasking paradigms successfully discriminate between frontal lobe patients who have difficulty organising their behaviour in everyday life and those who do not (Burgess et al., 2000). In support of their high ‘ecological validity’ (i.e., where test performance reflects real life performance), performance on multitasking tests has been demonstrated to relate to everyday life difficulties (Alderman, Burgess, Knight et al., 2003; Burgess, Alderman, Evans et al., 1998; Wilson, Evans, Emslie et al., 1998). Carers of brain injured patients rated their everyday executive difficulties using the specially designed Dysexecutive Questionnaire (DEX; Burgess, Alderman, Wilson et al., 1996), and these ratings were compared to the patients’
performance on several tests of executive function including the SET (Burgess et al., 1998). As a group the patients performed poorly on the tests of executive function and scored highly on the DEX (a higher score indicating greater difficulty). In general performance on the tests of executive function showed significant correlations with carers DEX ratings. The SET test correlated moderately with DEX ratings ($r = .40$) indicating that poor multitask performance is reflected in executive impairments in everyday life.

What do multitask tests involve? What cognitive functions are required to perform multitask tests? What is it about multitasking that is so difficult for frontal lobe patients?

Multitask tests involve the prioritisation, organisation and execution of a number of different tasks within a given period (Shallice & Burgess, 1991). The tasks in a multitask paradigm are interleaved with one another, meaning that they cannot be performed sequentially. This interleaving represents the demands made by performing multiple goal-directed actions in our everyday lives. In real life interleaving is achieved by situational constraints, going to work, collecting dry cleaning and buying food for dinner might involve being at work between 9 and 5, collecting dry cleaning before the shop closes at 5, and going to the supermarket after work. In multitask paradigms this interleaving is achieved by rules governing task performance. For example tasks of the same type are often paired into part A and part B. Participants are informed that they cannot perform parts A and B sequentially, this involves planning the order in which tasks are to be performed, rather like planning when to be at work, when to collect dry cleaning and when to go food shopping. Burgess (2000) recently summarised the key features of any multitask situation. (1) A number of discrete and different tasks have to be completed. (2) Performance on these tasks needs to be interleaved in order to be effective. (3) Due to either cognitive or physical constraints only one task can be performed at a time. (4) Unforeseen interruptions may occur and things do not always go as planned. (5) The intention to act is delayed as the time to return to a task which is already running is not signalled directly by the situation. (6) Tasks usually differ in terms of priority, difficulty and length of time they will occupy. (7) People usually decide for themselves what constitutes adequate performance. (8) There is no immediate feedback and failures are not signalled at the time they occur (Burgess, 2000, pages 281-282).
Burgess and colleagues (2000) designed a multitask paradigm to investigate the cognitive processes underlying multitasking. Their Greenwich multitask test involved only three tasks governed by a number of complex rules. In order to ascertain the cognitive processes contributing to multitasking, the test was administered as part of an invariant behavioural sequence, with measures taken at six stages generating six key variables. First, the participant’s memory for the rules of the game was assessed (learn), following which they were asked to generate a plan of how they would perform the three tasks (plan). The success with which this plan was subsequently implemented (follow), overall performance on the multitask test (score) and the individuals’ ability to evaluate their own performance (monitor) were also measured, following which memory for the rules of the task was tested once more (remember). Burgess and colleagues (2000) modelled the relationships between these six variables using structural equation modelling (SEM) and generated a 3-factor model of the processes underlying multitasking including: a retrospective memory factor, a planning factor and an intentional/prospective factor (see Figure 2.1). Retrospective memory represents memory for the tasks to be attempted and for rules of the task. Planning represents the ability to generate a plan of how to perform multiple tasks. The prospective/intention factor represents the ability to somehow execute this plan to successfully perform multiple tasks. The relationships between these underlying processes were also modelled; planning and prospective/intention factors draw upon retrospective memory, encouraging Burgess and colleagues (2000) to propose that retrospective memory supports planning and prospective/intention processes. The 3-factor model is illustrated in Figure 2.1.
Chapter 2: The organisation of future behaviour in adults

Figure 2-1: Structural Equation Model of Multitasking (Burgess et al., 2000)

Ellipses show the theoretical cognitive systems supporting multitasking, boxes show which multitask variable contributes to each construct.

Which aspect of multitasking presents particular difficulty to the patients with frontal lobe damage? The pattern of multitask performance in the patients with frontal lobe damage supports this model of three independent cognitive processes underlying multitasking. Interestingly, the patients were able to correctly recall the tasks or errands to be attempted, and the rules governing their performance, indicating preserved retrospective memory. In addition many of them could also generate a reasonable plan for how to perform the multitasks, indicating preserved planning ability. However, the patients were unable to implement the plans they had made or to adhere to the rules they had learned. This represents a failure of execution; despite being able to identify the goals of the task the patients somehow failed to achieve them (Shallice & Burgess, 1991). Consequently Shallice and Burgess (1991) identified the most important demand placed by multitask performance as “…the ability to create and activate delayed intentions” (Burgess et al., 2000: 849). Their patients were somehow unable to create or activate a representation of the steps necessary to achieve the goal, at the appropriate point in future time. Therefore the intention/ prospective factor represents the key cognitive process involved in the prospective organisation of goal-directed behaviour.
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Shallice and Burgess (1991) proposed that the process involved with the creation, maintenance and activation of delayed intentions involves the use of 'intention markers.' These markers are set up at the time when the intention (to act) is formed, and activated at a later point in time (when the intended action ought to be performed). This concept is not incompatible with other explanations designed to account for frontal lobe patients' failure to execute intended actions. Damasio proposed 'somatic markers' (Damasio, 1996) and Duncan 'goal neglect' (Duncan, 1986, Duncan et al., 1995, 1996) as explanations of the same phenomenon. Further support for the relationship between multitasking and intentionality comes from the study involving the DEX questionnaire mentioned above (Burgess et al., 1998). The DEX questionnaire measures the consequences of brain injury across five domains of executive function including inhibition, intentionality, executive memory and positive and negative affect. The SET is the only test to load onto the intentionality factor, which represents executive skills involved in the creation and maintenance of goal-directed behaviour.

The means by which 'intention markers' control future behaviour are interpreted within the framework of the 'Supervisory Attention System' (SAS); a model of the processes involved in the control of goal-directed behaviour (Norman & Shallice, 1986; Shallice, 1988; Shallice & Burgess, 1996). The SAS model is discussed in the section below and illustrated in Figure 2.2.

2.1.3 The supervisory attention system

In this model everyday action is organised by schemata "...the basic units underlying action or thought..." (Shallice, 1988: 332) which are hierarchical in nature and operate on two levels. At a lower level, appropriate actions are selected via a process of 'contention scheduling.' Parameters of any given situation ('input triggers') activate multiple schemata which compete against one another for selection; the schema which matches the 'input triggers' most closely reaches threshold above competitors and is therefore selected automatically. A selected schema will remain active until its goal is attained or it is actively inhibited by a competitor or higher-level controlling schema (1988: pages 332-333). By using a hierarchy of schemata the theory can account for the ease with which we learn and perform many automated behaviours and actions. It is during changes to a routine situation, when a relatively automatic programme of action is selected where an alternative should be enforced, that everyday 'slips of action' occur (Norman and Shallice, 1986).
Figure 2-2: The Supervisory Attentional System (Shallice & Burgess, 1996a, 1998)

Dotted rectangles represent the 3 different stages. Circles represent temporally distinct phases of supervisory system processing. Solid rectangles represent an operation which corresponds to a change-of-state of one or more control variables. Solid lines between the stages represent the flow of control between operation of different stages or between supervisory system and contention scheduling. Unfilled lines represent information transfer used in monitoring operations.
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At a higher level, top-down or ‘executive’ processes control goal-directed behaviour in complex, attentionally demanding or non-routine (novel) situations. The SAS model proposes that in a novel situation a temporary new schema is constructed to organise action, this process involves three stages: (1) the construction of a temporary new schema; (2) the implementation of the temporary new schema; and (3) the assessment and verification of the temporary new schema. Each stage involves a number of sub-component processes. The first process involved in the construction of a temporary new schema is an initial ‘problem orientation phase’ during which a new schema can either be spontaneously generated by ‘affordances’ of the problem situation, or by a more conscious ‘effortful problem-solving process.’ Once the ‘problem-orientation phase’ is complete, a ‘goal-setting process’ is initiated which is followed by a ‘strategy generation phase’, a ‘progressive deepening phase’ (for complex problem situations) and a ‘solution checking phase’. At any point during the construction of a temporary new schema, existing knowledge gained from experience can be tapped into to inform on schema construction, via an ‘episodic memory retrieval process.’ Most pertinent to this review, the model incorporates a ‘delayed intention marker realisation process,’ whereby implementation of a temporary new schema (stage 2) can be delayed until a future point in time. As its name suggests, the Supervisory System acts within the confines of finite attentional resources and working memory capacity. For a new schema to be implemented, special purpose working memory, (holding information particular to that schema), is required. At stage 3 the temporary new schema is assessed and verified via a ‘monitoring process’ and if necessary rejected by a ‘rejection process.’ Processes at stage 3 feed back to stage 1 (temporary new schema creation) so that aspects of the schema can be re-constructed in response to monitoring.

The Supervisory Attention System as a whole is well supported by neuropsychological and experimental data (e.g., Burgess and Shallice, 1996a,b, 1998; Norman & Shallice, 1986; Shallice, 1988; Shallice & Burgess, 1991, 1996), and an evaluation of the whole model is beyond the scope of this review. Instead, we shall focus on the process in the model most closely related to the organisation of future behaviour the ‘intention generation and realisation process’ which sets up ‘intention markers’ to cue actions at future points in time.
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The process of creating and realising a delayed intention has been termed prospective memory. Prospective memory has been identified as the key cognitive process underlying the organisation of future goal-directed behaviour. In addition retrospective memory and planning also have roles in the organisation of future behaviour. Planning is an executive function and there is evidence that other executive functions also contribute to the organisation of future actions (see below). The roles of prospective memory, retrospective memory, planning and executive functions in the organisation of future goal-directed action are reviewed in the sections that follow.

2.2 The realisation of delayed intentions - prospective memory

The process of creating and realising a delayed intention has been termed Prospective Memory (PM). Recent years have seen a growing interest in this somewhat new field of psychology (Brandimonte, Einstein & McDaniell, 1996) chiefly due to the relevance of prospective memory to everyday life (Kliegel & Martin, 2003). Prospective memory been identified as the key psychological process involved in the organisation of future behaviour (e.g., Burgess et al., 2000; Burgess & Shallice, 1997; Einstein & McDaniel, 1990; Ellis, 1996). Prospective memory is recognised as an important cognitive skill for living independently in the community (Cockburn & Smith, 1988; Groot, Wilson, Evans et al., 2002; Sinnot, 1989). Prospective memory deficits are also profoundly disabbling as they impact upon an individual’s ability to organise their everyday life (Kliegel & Martin, 2003; Mills, Kíxmill, Gillespie et al., 1997). Moreover, it is becoming increasingly clear that at least 50% of everyday memory problems in the normal population are prospective in nature (e.g., Crovitz & Daniel, 1984; Terry, 1998), and that some aspects of prospective memory are vulnerable to the effects of normal ageing (Einstein, McDaniel, Richardson et al., 1995; Maylor, 1996).

PM has variously been defined as ‘memory for future actions’ (Einstein & McDaniel, 1996, Mantyla, 1996), ‘remembering intentions’ (Kvavilashvili & Ellis, 1996) and ‘intention memory’ (Goschke & Kuhl, 1996). PM is not universally accepted as a form of memory independent from retrospective memory (e.g. Crowder, 1996; Roediger, 1996); one outstanding problem relates to the ‘content based’ definitions of PM given above (Graf & Uttl, 2001). The danger is that defining PM on the basis of its
content fails to distinguish it from forms of retrospective memory; there is nothing to prove that ‘memory for future intentions’ is any different to ‘memory for faces’ or ‘memory for words’ (Graf & Uttl, 2001). Definitions of PM have been broadened to highlight the unique processes involved in this form of memory, for example defining PM as the ‘delayed execution of an intended action’ (Kliegel & Martin, 2003). There is a growing body of evidence to support PM as a unique psychological construct, independently identifiable albeit inherently linked to retrospective memory.

One way to differentiate prospective memory from retrospective memory is by its unique use of ‘memory cues’ (Graf and Uttl, 2001). In the terminology of the Supervisory Attention System, memory cues equate to ‘intention markers.’ Retrospective memory "...begins with cues, with recognised telltale signs, and... uses these as guides for recovering prior episodes, events and experiences..." (Graf & Uttl, 2001:441). Whereas, “...the prospective function of memory is required for situations where telltale signs have to be recognised so that recovery operations can be initiated..." (Graf & Uttl, 2001: 441). In other words, where retrospective remembering begins with a ‘well recognised’ memory cue, successful prospective remembering involves being able to recognise the relevant memory cue embedded within any given situation.

2.2.1 Types of prospective memory

Different types of PM can be identified based upon the nature of the ‘to-be-remembered’ intention, the way in which the intention is cued at a future point in time and the length of time over which the intention is delayed. Whether these reflect distinct subtypes of PM or represent a continuum is yet to be determined (Graf & Uttl, 2001). Routine ‘to-be-remembered’ intentions (e.g., regularly taking medication) are conceptualised as habitual PM and non-routine prospective intentions as ‘episodic’ PM. The cue to activate a ‘to-be-remembered’ action can be ‘event-based’ i.e. when ‘a’ occurs do ‘b,’ or ‘time-based’ - at time ‘x’ do ‘y’. The length of time over which an intended action is delayed is believed to influence how the intention is stored. Over short delays, maintenance of the ‘to-be-remembered’ intention may be via continuous conscious rehearsal in short-term or working memory, such as in vigilance tasks (press button every time you hear tone). Over longer delays, the to-be-remembered intention is retained outside of the current focus of attention, presumably in long-term memory, to be retrieved at a later point in time (Graf & Uttl, 2001). The storage of intentions clearly
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raises the possibility of a close relationship between retrospective and prospective memory, an issue which will be discussed in greater depth shortly.

2.2.2 Testing prospective memory

Most research into prospective memory has focused on the prospective remembering of 'one-off' episodes where the cue to perform the 'to-be-remembered' intention is 'event-based' and occurs after a delay, requiring that the prospective intention be held in long-term memory outside of current attention. These aspects of PM can be manipulated and controlled in a laboratory setting. The standard PM paradigm was first conceived by Einstein and McDaniel (1990) and the majority of research in the field has used variations of this paradigm ever since. In this computerised paradigm, participants perform an ongoing retrospective memory task during which they attempt to remember lists of words presented on a computer screen. The prospective memory task (PM task) is embedded within the ongoing task, and involves pressing the spacebar in response to particular words (for example animal words, words beginning with W, nonsense words). Embedding the PM task within an ongoing task enables delay of the intended action (by time spent performing the ongoing task) and prevents active rehearsal of the intended action in STM or WM (as attention is focused on the ongoing task). When the PM cue appears it must be activated and the participant must switch attention from the ongoing task to the PM task (to the 'to-be-remembered' action). All aspects of this situation can be controlled and manipulated, including the level of processing required by the ongoing task, the salience of the PM cue, the delay after which the PM cue appears and so on. Evaluation of these manipulations has revealed many of the processes involved in and constraints placed upon prospective remembering. These are discussed below in the framework of 'Multiprocess Model' of prospective memory (McDaniel & Einstein, 2000; updated by Kliegel, Martin, McDaniel & Einstein, 2002).

2.2.3 The 'multiprocess framework' of prospective memory

The unique use of 'cues' is central to prospective remembering (Graf & Uttl, 2001). It is 'cue recognition' which causes the switch in attention from the ongoing/foreground task to the PM task enabling us to remember to carry out intended actions. Whether the 'switch' is successful and whether this results in the prospective action being carried out, depends on features of the PM cue itself
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(McDaniel & Einstein, 2000). The 'multiprocess framework' explains how a PM cue is recognised and retrieved (McDaniel & Einstein, 2000). The 'multiprocess framework' has recently been revised to the 'process model of prospective memory' detailed in Figure 2.3 (Kliegel et al., 2002). The process of prospective remembering is sub-divided into four stages: intention formation, intention retention, intention initiation and intention execution. At the intention formation and intention execution stages, cue recognition and retrieval can be either automatically or consciously controlled. The mechanism that determines the level of processing involved is the PM cue itself.

Figure 2-3: The process model of prospective memory (Kliegel et al., 2002)

The multiprocess framework is concerned with identifying how the PM cue is recognised and retrieved at the appropriate point in future time (the intention initiation phase). Critically for the PM cue to come to attention (conscious or automatic), attentional resources must be switched from the ongoing activity to the intended action. It is this shift in attention which the multiprocess framework proposes can be both automatic and involuntary, and/or conscious and controlled. Which of these levels of processing is recruited depends on the many factors. The PM system operates within a limited capacity processing space (determined by allocation of attention). As discussed previously, the realisation of delayed intentions is one process among many within a broader system modelling the control of goal-directed behaviour (Burgess et al., 2000). Clearly performance on prospective memory tasks will be influenced by many factors other than prospective memory processes; the strength of the multiprocess framework is in assessing the relationship between the PM cue, the ongoing task and the PM task in prospective remembering.
2.2.4 The prospective memory cue

Prospective remembering is achieved by a system that sets up and subsequently recognises and initiates prospective memory cues. Aspects of the PM cue itself influence PM performance and provide lots of information about the cognitive processes that support PM retrieval. At the recognition/intention initiation stage, the more distinctive the cue, the more it will serve as a unique prompt to switch attention from the ongoing task to the PM task. For example presenting target PM words (e.g. animal words amongst other categories) in UPPER CASE makes them distinct and serves as a reminder to respond to them (Brandimonte & Passolunghi, 1994; Einstein et al., 2000). A salient target may be not only facilitate the switch in attention from the ongoing activity to thinking about the prospective activity, it may also provide a frame of reference enabling the individual to quickly recognise the significance of the target cue and initiate the intended action. The more distinctive the cue, the more automatic PM retrieval is. Conversely, there is evidence that when the cue is less distinctive, PM performance suffers; this is particularly true for older adults (Einstein et al., 2000). It is possible that less distinctive cues requires greater processing resources which are reduced in older adults (Salthouse, 1996, 2000) and are hence more likely to be affected by this. Manipulating available processing resources in younger adults (by adding a secondary task) does not affect PM performance with distinctive targets, but does for less salient targets/ cues (Einstein et al., 2000). At the set up/ intention formation stage, the strength of association between the PM cue and the intended action influences the extent to which the PM cue (at recognition/ initiation) is processed automatically or effortfully. A strong association between the target event and the to-be-remembered action, e.g., 'on approaching the bank, get cash out,' is more likely to be processed automatically without much conscious thought (Guynn, McDaniel & Einstein, 2001). However if the association is less strong, or if it differs from a normal procedure, more conscious processes will be recruited to ensure the action is taken. For example, 'on approaching the bank - go inside to make an appointment with the manager,' may require greater conscious control both to 'remember to do' this infrequent event, and to override the more automatic response to being at the bank (taking cash out). Failure of the system to override this automatic response could result in a 'slip of action' akin to those described in the Supervisory Attention System (Norman & Shallice, 1986).
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2.2.5 The ongoing task

In addition to parameters of the PM cue, the characteristics of the ongoing or 'to-be-interrupted' task can also inform on the processes underlying prospective memory. The way in which the PM cue is processed is likely to have an effect on whether it leads to automatic or voluntary retrieval of the 'to-be-remembered' intention. If the PM cue is presented as a focal part of the ongoing task, it is more likely to be processed sufficiently to enable automatic retrieval of the intended action (McDaniel & Einstein, 2000). For example, in an ongoing task involving naming picture cards, the PM cue is an animal card, thus the PM cue is processed as the focus of the ongoing task (named) and the 'to-be-remembered' action is more likely to be retrieved automatically upon presentation of the cue. If, on the other hand, the PM cue is not an integral part of the ongoing task, further resources will be necessary to monitor the environment (internal or external) for the occurrence of the PM cue to signal the appropriateness of performing the intended action (McDaniel & Einstein, 2000; Maylor, 1996). Supporting evidence comes from studies with older adults, whose prospective remembering is more vulnerable when the PM cue is not part of the ongoing task (Maylor, 1993, 1996). Within a limited capacity system the extent to which participants become absorbed in the ongoing activity can clearly influence PM performance. Broadly speaking, the more absorbing the ongoing activity - the fewer attentional resources available for recognition and activation of the PM cue – thus the more PM performance is affected (Kvavilashvili, 1987). This finding may not only relate to how absorbing the ongoing task is; it is also likely to reflect how complex or attentionally demanding the ongoing task is. In a study aimed at identifying the frequently reported discrepancy between older adults superior PM performance in everyday life compared to their performance on laboratory tasks, Rendell and Craik (2000) asked younger and older adults to perform PM tasks as part of an 'actual week' or a 'virtual week.' The actual week task involved participants incorporating a number of prospective tasks into their everyday life, such as attending meetings or posting letters. The virtual week was computer based and involved computerised planning and enactment of similar tasks in a virtual reality environment (although obviously working in a shorter time scale). The authors found that older participants found the virtual week PM tasks more demanding and performed these more poorly than actual week PM tasks which they incorporated successfully into their everyday activities. They concluded that the virtual week task itself was a more demanding, involved and concentrated set of ongoing activities than the actual week task, and as such placed greater demands on the elderly participant's limited capacity processing.
systems at the expense of prospective remembering. See also Rendell & Forbes (unpublished, cited in McDaniel & Einstein, 2000) for similar data using famous face stimuli, where less demanding face processing using age-judgements rather than face naming eliminated observed age-related declines in PM performance on this task.

2.2.6 The prospective memory task

The significance of the prospective memory task (importance to the individual or importance perceived by the individual) can also influence PM task performance (e.g. Kliegel, Martin, McDaniel & Einstein, 2001). In most situations people manage to perform important prospective tasks without affecting performance on intermediate ongoing tasks. However, in situations where the PM task places high demands on attentional resources (e.g. a time-based PM task), participants who perceive the PM task to be most important prioritise it at the expense of performance on the ongoing task and subsequently perform the PM task significantly better than control participants who have no beliefs regarding task importance (Kliegel et al., 2001). In event-based PM tasks, which place fewer demands on processing resources, participant’s attentional resources must be stretched further (e.g., by adding a secondary task) before this effect is repeated. Further evidence of the influence of task importance on performance comes from a study of older adults whose processing capacity is more limited than that of younger adults. Older participants who believed the ongoing task to be more important than the PM task outperformed younger adults on the ongoing task, to the detriment of PM task performance; clearly making the decision to ‘trade up’ performance on the ongoing task at the expense of the PM task. Conversely, the younger adults who had greater processing resources available were able to perform both tasks satisfactorily (Kliegel, 2003a). Finally, motivation may also come from the true value of the prospective task as well as the instructed or perceived value. Winograd (1988) mentions the policy of dentists in the USA who give patients a ‘reminder call’ the day before an appointment, he wryly notes that hairdressers do not need to adopt a similar policy. In contrast to this observation, the ‘value’ of a borrowed object in a real life PM task did not help neurological patients (most with suspected dementia) to remember to get it back (Bakker, Schretlen and Brandt, 2002). This study serves as a reminder that whilst investigations of atypical populations can be very informative in research at both ends of the developmental spectrum, they may also be misleading reflecting
alterations in an atypically developing or ageing system which may be dependent on an altered cognitive architecture.

Through its use of a limited capacity system, the multiprocess framework is able to incorporate many of the seemingly divergent findings evidenced in the PM literature. Most significantly, the framework can account for contradictory findings in the ageing literature where some studies report consistent age-related reductions in prospective remembering (e.g. Craik, Anderson, Kerr et al., 1995; Maylor 1993, 1996; Park et al., 1997; Uttl & Graf, 2000) whilst others do not (e.g., Cherry & LeCompte, 1999; Einstein & McDaniel, 1990; Einstein et al., 1992, 1995, 1997).

2.2.7 The multiprocess framework and the supervisory attention system

Many parallels can be drawn between these two models. McDaniel and Einstein's (2000) multiprocess framework outlines two routes to prospective remembering. An automatic route (where there is a high association between prospective memory cue and intended action) and an effortful, consciously controlled route (necessary where the association is poorly defined, or involves overriding an existing link which biases attention). The SAS proposes three routes to goal-directed behaviour, one of which is prospective; operating on two levels of control. In the SAS model the role of future intentions in the organisation of goal-directed behaviour is only included at the higher level of control, via the creation of intention markers as part of a ‘temporary new schema construction process.’ Clearly this level of explanation fits McDaniel and Einstein's voluntarily controlled route towards prospective remembering. Both models incorporate the generation of markers for future intentions (intention markers & PM cues).

In the conscious or strategic control of prospective remembering, the SAS is involved in encoding the association between the PM cue and the intended action. It is also vitally involved in monitoring the environment for the occurrence of this PM cue to signal the appropriateness of performing the intended action; finally the SAS strategically interrupts the ongoing task to provide opportunity to execute the intended activity (Burgess & Shallice, 1996a; Ellis, 1996). Einstein and McDaniel propose a number of ways in which this voluntary monitoring process could work. Some executive processes could be continuously directed to monitoring the environment for cues, which may explain why cue type and the nature of the ongoing task affect performance. In support of continuous (sub-conscious) monitoring of the environment Smith (2000) demonstrated that participants who simply received, but did not have to
implement, PM instructions (as no PM cues were presented) performed differently on the ongoing task compared to controls who had received no PM instructions. The SAS could also be responsible for ‘bringing to mind’ an intention, as is sometimes reported in phenomenological accounts (e.g. Kvavilashvili, 1987).

McDaniel & Einstein (2000) propose a number of processes that may support automatic prospective remembering. An exogenous attentional process may involuntarily orient the individual to salient or unusual stimuli which cue the to-be-remembered intention (if this action is complex, a controlled search of memory may follow). An ‘associative memory-based’ automatic process may form strong associations between the PM cue and the intention; automatically leading to the intention being implemented upon presentation of the PM cue. A ‘familiarity plus search’ process may also support prospective remembering (Einstein & McDaniel, 1996) by automatically invoking a feeling of familiarity, leading to a search of prospective memory for the relevant intention. The SAS does not explicitly include a role for automatic prospective remembering, although it is possible to imagine where lower level processes could be incorporated into the system. Automatic recognition of PM cues/ delayed intention markers could be achieved through the process of ‘contention scheduling’ whereby potentially relevant PM cues would compete for recognition, with the most relevant PM cue becoming the most active hence automatically being selected to guide behaviour. It is likely that such automatic processes could serve habitual prospective remembering in routine situations such as taking regular medication, although this remains speculative at present.

Further support for the role of the SAS in prospective remembering comes from research into the ‘intention superiority effect’ (ISE). The ISE refers to the finding that intention information appears to hold a privileged place in memory being more accessible than neutral information not associated with an intention (Dockree & Ellis, 2001; Goshke & Kuhl, 1993; Marsh, Hicks & Bink, 1998). In an ISE paradigm, participants learn pairs of action scripts, e.g., ‘set the table,’ some of which are to be retained for future enactment whilst others are not (neutral pairs). When participants perform a subsequent word recognition task, their response latencies for words from ‘to-be-enacted’ scripts are faster than latencies for words from neutral scripts (Ellis, 1996). Explanations of the ISE support the SAS model. Intention information is processed rapidly and efficiently by an intention marker which
provides an internal context cue that is triggered once retrieval conditions have been satisfied (Marsh, et al., 1998). Once an intention marker (PM cue) has been triggered, the intended material is harder to remember: response latencies for words from ‘already performed’ scripts are significantly longer indicating that completed actions are inhibited, probably to prevent them being performed again by mistake (Marsh et al., 1998). Likewise, information about cancelled intentions is equally suppressed in memory, reflecting the reality that multiple intentions are formed and then cancelled as part of our everyday lives (Dockree & Ellis, 2001). The superiority of intention information is thought to be achieved at the encoding stage when intention markers are set up. Inhibition of performed or cancelled intentions is achieved via “…the firing of action schemas that laterally inhibit other activated but redundant activities…” thereby freeing processing space in working memory (Dockree & Ellis, 2001: page 1143). The lateral inhibition of action schemas is achieved at the contention scheduling level of the SAS; indicating a probable role for both supervisory and automatic levels of control in prospective remembering.

2.2.8 Complex prospective memory

Research into ‘complex prospective memory’ grew out of an increasing recognition that prospective memory in everyday life is essentially employed in complex environments and that prospective remembering requires the creation and activation of multiple rather than single delayed intentions (Kliegel et al., 2000, 2002). Prospective memory failures are linked to deficits in performing activities of daily living (ADL) in patients with brain injury in naturalistic studies (Fortin et al., 2002; Mills et al., 1997). Complex prospective memory is tested using multitask paradigms (‘multi-intention’ tasks) and involves executive control processes in addition to prospective memory processes (Kliegel et al., 2000, 2002). Complex prospective memory forms a key research area when investigating the cognitive processes underlying the organisation of prospective actions in everyday life.

Performance at all four stages of the process model of prospective memory can be measured when a multitask paradigm is used to test complex PM (Kliegel et al., 2002). These multitask tests of complex PM have been based on Shallice and Burgess (1991) Six Elements Test (SET) and include a modified paper and pencil version (Kliegel et al., 2000) and a more recently developed computerised version (Kliegel et al., 2002). Although both complex PM tests are based on the SET, in that they involve
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Performing multiple tasks under rule and time-based constraints, they have been administered in a more structured way. Participants learned the rules of the paradigm and generated a plan of how they would perform the tasks (intention formation). Participants were instructed that at the appearance of a pre-determined stimulus (writing their date of birth on a questionnaire), they should begin the complex PM task (intention initiation). Following this instruction period there was a delay during which participants performed an unrelated task and their memory for their plan was assessed (intention retention). After this delay the questionnaire was presented to participants and at this point they were supposed to begin performing the complex PM task (intention initiation); the experimenter reminded participants who did not do this. Finally task performance itself was assessed (intention execution). With the exception of the delay period and repetition of the plan, the administration of the complex PM tests resembles the administration procedure used for the Greenwich multitask test (Burgess et al., 2000), discussed in section 2.1.2.

Kliegel et al. (2000) administered their complex PM test to a group of young adults (mean age 26 years) and a group of older adults (mean age 71 years) and found evidence of age related impairments in complex PM at some but not all stages of the model. Older adults produced less elaborate plans than younger adults did; however they were just as good at retaining this plan over a delay as young adults (plan retention). Significant age group differences were also observed for plan initiation; younger adults were more likely to remember to self initiate their plan than older adults were. Finally when performing the complex PM test, younger adults attempted significantly more sub tests than older adults did (Kliegel et al., 2000). In addition to investigating age group differences in complex prospective memory, the authors also investigated the contributions of executive functions of prospective memory performance. They found evidence to support the differential involvement of executive processes at different stages of the process model (Kliegel et al., 2000; Kliegel et al., 2002). Executive functions involved in prospective remembering include planning, inhibitory control and cognitive flexibility. This evidence will be discussed in greater detail in section 2.4.1 below.

In sum, prospective memory is the key cognitive process involved in the creation and realisation of delayed intentions, a cognitive skill vital for the prospective organisation of actions in everyday life. Prospective memory relies upon the use of internal or external cues to guide behaviour. A four-stage
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model of prospective memory has been introduced, which operates on two levels of control, according to features of the prospective memory cue. This model has been compared to the supervisory attentional system model discussed in the previous section. Different types of prospective memory have been identified; the most important of these is complex prospective memory as this represents the form of prospective memory most relevant to everyday life. Research into complex prospective memory employs multitask paradigms. Performance on multitask paradigms is typically impaired in adult patients with frontal lobe damage who have difficulties organising future actions. Performance on tests of complex prospective memory also shows age-related declines, indicating that the prospective organisation of action may also be vulnerable in normal ageing. Research has probed the cognitive processes underlying performance on complex prospective memory tests; results support a similar set of underlying processes to those proposed as a result of parallel investigations in adult neuropsychology (Burgess et al., 2000). These include prospective and retrospective memory, and extend our knowledge of the influence of executive control functions in complex prospective memory to include planning, inhibitory control and cognitive flexibility. The roles of retrospective memory and executive functions in the organisation of future behaviour are discussed below.

2.3 Retrospective memory and the organisation of future behaviour

Critics of prospective memory dismiss it as a form of retrospective memory, distinct only in terms of the methodology employed to investigate it and its content of ‘memory for intentions’ (e.g., Crowder, 1996; Roediger, 1996). Indeed, previous ‘content-based’ definitions of PM did little to promote the unique contribution of PM to cognitive functioning. However researchers in the field are confident that recent conceptualisations of PM and the development of cognitive models of PM, such as the ‘multiprocess framework’, support PM as a viable cognitive process in its own right. There is undoubtedly a relationship between prospective and retrospective memory and this relationship is of great theoretical interest (see Burgess & Shallice, 1997, for a review). The extent to which these forms of memory recruit the same psychological processes merits further investigation, which could be achieved using tasks which give separate indexes of the pro- and retrospective components of prospective remembering (Graff and Uttl, 2001). It is likely that developmental studies in children as well as in older adults can inform on this question.
Prospective memory has a retrospective component in the form of the content of the ‘to-be-remembered’ intention (McDaniel & Einstein, 1992). How many times in your life have you walked into a room and completely forgotten what it was you entered the room to fetch, say or do? In this situation the prospective intention is activated (upon entering the room check memory for intention X), but the retrospective record of what was intended has disappeared. The potential influence of the retrospective component of prospective remembering is controlled in PM paradigms, as participants must be able to demonstrate knowledge of the PM task prior to the onset of testing (e.g., Kvavilashvili, 1998).

Neuropsychological studies suggest a single dissociation between retrospective and prospective memory, indicative of a one-directional dependent relationship between them (Burgess & Shallice, 1997). Densely amnesiac patients with impaired retrospective memory also show impaired prospective memory functioning (Alderman & Burgess, 1993; Davies & Binks, 1983; Wilson, 1987). Patients with intact retrospective memories can exhibit prospective memory difficulties, such as Shallice & Burgess (1991) patients described earlier (see also Atance & O’Neill, 2001b; Eslinger & Damasio, 1985; Duncan et al., 1995; Goldstein et al., 1993). However, evidence does not exist to support patients who have retrospective memory problems in the face of intact prospective memory; indicating a relationship between RM and PM whereby retrospective memory is a necessary precursor to prospective memory (Burgess & Shallice, 1997). Relationships between performance on measures of prospective and retrospective memory have been reported in patients with brain injuries of mixed aetiology (e.g., Groot et al., 2002), supporting a relationship between these two forms of memory.

Further support for a single dissociation between prospective and retrospective memory comes from studies of normal ageing in which the balance of evidence suggests differential trajectories for these two forms of memory. Whilst retrospective memory declines are well documented (e.g., Craik, Anderson, Kerr et al., 1995; Zacks, Hasher & Li, 2000), prospective memory declines are more variable (see Maylor, Darby, Logie et al., 2002 for a review). Middle aged women recruited from the community who self reported severe prospective memory difficulties showed impaired prospective memory performance relative to matched controls; neither group showed impaired retrospective memory performance, supporting the separation of these constructs in the course of normal ageing (Mantyla,
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2003). Another way to investigate the relationship between prospective and retrospective memory is to compare prospective and retrospective performance on tasks that test both types of memory. Prospective memory tasks are typically embedded within an ongoing retrospective memory task such as recalling a word list, providing the opportunity to assess both forms of memory using the same stimulus materials (Einstein & McDaniel, 1990). A number of studies with adults have found that these different aspects of performance correlate weakly, if at all, suggesting that these memory processes are distinct (e.g., Brandimonte & Passolunghi, 1994; Einstein & McDaniel, 1990; Kidder, Park, Hertzog et al., 1997; Uttl, Graff, Miller et al., 2001). It has been suggested that RM and PM correlate more highly when the retrospective component of the prospective act is more complicated, such as remembering a long shopping list (Einstein & McDaniel, 1990). Factor analysis of retrospective and prospective memory task performance in young and older adults has revealed separate RM and PM factors, although these are related to one another supporting a one way dissociation between them (Maylor, Smith, Della Sala et al., 2002). This result from laboratory studies was replicated in a real life setting using a questionnaire assessing everyday memory failures; independent RM and PM factors were observed (Crawford, Smith, Maylor et al., 2003).

All this evidence fits the model of the cognitive processes underlying multitasking discussed earlier, in which retrospective memory supports prospective memory but remains independent of it (Burgess et al., 2000). In the process model of prospective memory, retrospective memory is involved in retaining the details of the intended action (Kliegel et al., 2002). In conclusion, retrospective and prospective memory are separate cognitive processes, although they are not unrelated. Specifically, retrospective memory is a necessary precursor for successful prospective memory, due to its role in retaining information about the content of an intended action.

2.4 Executive functions and the organisation of future behaviour

Multitasking paradigms were designed to address an apparent confound in the performance of frontal lobe patients, namely their relatively intact performance on traditional tests of frontal lobe function in contrast to a grossly impaired ability to make decisions and organise activities in their daily lives. Traditional cognitive testing is frequently done in a quiet environment in which the patient is assessed
one-to-one by an examiner. The tests typically include solving a single explicit problem at a time and the goal of the test is normally provided by the examiner (such as in the Tower of London where the 'goal state' is modelled for the patient). In contrast to this highly structured situation, planning and organising in everyday life takes place in an arena full of distractions and interruptions, where multiple intentions are processed over the course of a day and tasks compete with one another for level of priority. Performance on these traditional tests of executive function dissociates from performance on multitask tests (Burgess et al., 1998). Five factors were derived from a questionnaire designed to capture many of the behaviours typically displayed by adult patients with frontal lobe damage: inhibition (deficits in response suppression and disinhibition), intentionality (everyday deficits in planning and decision making), executive memory (e.g. confabulation, perseveration) and positive and negative affective changes. Of these five only the 'intentionality' factor correlated with performance on a multitask paradigm, ten other traditional tests of executive function did not. This suggests that the processes that underlie multitask performance may be distinct from the executive processes measured by traditional tests of executive function. In other words the cognitive processes underlying the organisation of future action in everyday life may be a distinct set of processes (Burgess, 2000).

Recent investigations indicate that whilst the cognitive processes underlying the organisation of future action are indeed a distinct set of processes, traditional frontal executive functions still play a role at many stages of the organisation of future behaviour (e.g. Atance & O'Neill, 2001b; Groot et al., 2002; Kliegel et al., 2003, McDaniel et al., 1999). The Supervisory Attention System is itself a model of the executive control of goal-directed behaviour. It is possible that a single dissociation exists between executive functions and the organisation of future behaviour. Patients can have intact performance on traditional tests of executive function but demonstrate an impaired ability to act as an executive organiser in their day-to-day lives (e.g., Shallice & Burgess, 1991). Likewise patients who demonstrate frontal executive deficits on traditional tests of frontal lobe function also display difficulties in everyday life (e.g., Ackerly, 1964; Atance & O'Neill, 2001b). The converse situation of impaired executive abilities and spared organisation of future behaviour has not been reported (e.g., Burgess, 2000; Levine, Black, Cabeza et al., 1998a). Evidence supporting the role of executive processes in the organisation of future behaviour is reviewed in the sections that follow.
2.4.1 Executive functions and prospective memory

Studies of executive involvement in prospective memory have yielded mixed results, with some supporting executive involvement in prospective remembering (e.g., Bisiacchi, 2000; Burgess, 2000; Burgess et al., 2000; Cherry & LeCompte, 1999; Groot et al., 2002; Kopp & Thone, 2000; McDaniel et al., 1999), and others finding no evidence of a relationship between performance on EF measures and PM performance (e.g., Bisiacchi, 1996; Cockburn, Keene & Hope, 2000; Martin, Kliegel, McDaniel & Einstein, 2000). It is likely that these seemingly conflicting results may be explained by the specific demands of the prospective memory paradigm studied and the executive functions measured (Martin, Kliegel & McDaniel, 2003). Some prospective memory tasks are likely to place higher demands on executive processes than others; some executive functions are more likely to be involved in prospective remembering than others.

Neuropsychological studies support a relationship between prospective memory and executive functions (e.g., Groot et al., 2002; McDaniel, Glisky, Rubin et al., 1999; Miotto & Morris, 2000). Patients with brain injury of varying aetiology (e.g., traumatic, cerebro-vascular accident - CVA), were tested on a battery of prospective memory tests and an array of executive function and retrospective memory tasks (Groot et al., 2002). Patients were impaired relative to controls on the tests of prospective memory, which included time-based and event-based PM tests. In both patients and controls, prospective memory performance correlated with performance on tests of executive function measuring inhibitory control (Stroop), cognitive flexibility (Wisconsin Card Sort Test, Trails Test part B), working memory (digit span) and multitasking (modified six elements test). Performance on another test of executive function (the 'self ordered pointing task') also correlates with performance on the Six Elements Test (Duncan, Johnson, Swales et al., 1997). Furthermore, prospective memory performance in normal ageing correlates with the integrity of frontal lobe functioning but not medial temporal lobe functioning (McDaniel et al., 1999). Older adults performed executive function tests known to be sensitive to frontal lobe (FL) functioning and retrospective memory tests known to be sensitive to medial temporal lobe (MTL) functioning. The sample was first divided into high versus low FL groups, then high versus low MTL groups, based upon performance. High functioning FL participants performed better on tests of PM than low functioning FL participants; no such group difference was observed when participants
were grouped by MTL performance instead. These results support significantly greater frontal than medial temporal involvement in prospective memory performance.

To investigate the role of executive functions in prospective memory, Martin and colleagues (Martin et al., 2003) assessed performance of younger and older adults on four prospective memory tasks and three executive function tasks. The PM tasks varied in the degree to which they involved executive processes. A single task PM task (Wilson, Cockburn & Baddeley, 1985) had a low executive load as performance on this PM task is thought to rely most heavily on the maintenance and re-instantiation of intentions. An event-based PM task had slightly higher executive component and a time-based PM task placed more executive demands on monitoring processes at the ‘intention realisation’ stage. Finally a complex prospective memory task (a modified multitask paradigm) was hypothesised to have the highest level of executive involvement and involve executive processes at both the ‘intention formation’ and ‘intention realisation’ stages. Results supported the hypothesis that there is a relationship between executive function and prospective memory; and that the strength of this relationship is dependent on the extent to which the PM task places demands on executive processes. The single task PM task did not correlate with EF performance, whilst event-based, time-based and complex PM task performance correlated with EF performance to increasingly greater degrees.

Kliegel and colleagues (Kliegel et al., 2002; Martin, et al., 2003) propose the differential involvement of executive functions at each of the four stages of their model of prospective memory, with greater executive involvement at the ‘intention formation’ and ‘intention realisation’ stages and lesser executive contributions to the intermediary ‘intention maintenance’ and ‘re-instantiation of intention’ stages. This model, including the contributions from executive functions, is illustrated in Figure 2.4.
Evidence to support the differential involvement of executive processes at each stage of the model comes from studies involving tests of complex prospective memory, as this form of prospective memory has the greatest executive requirements (Kliegel et al., 2000; Kliegel et al., 2002). Adults performed the computerised complex PM task alongside measures of executive functions including two tests of fluency (verbal and non-verbal), the Wisconsin Card Sort Test which measures cognitive flexibility, the Stroop test which measures inhibitory control, the Tower of London test measuring planning and the 'Plan a Day' task (Funke & Kruger, 1993) measuring everyday planning skills (Kliegel et al., 2002). After age and performance on other tests of executive function has been accounted for, planning remained most robustly associated with the intention formation phase and explained 44% of the variance at this stage of the model, indicating that planning is the most important executive function underlying intention formation. No measures of executive function were associated with intention retention phase, indicating low executive involvement at this phase of the model. Executive function test performance in general explained 47% of the variance at the intention initiation phase; however no test really stood out against the others. Tests of cognitive flexibility, planning and non-verbal fluency
were significant predictors of intention execution, explaining 58% of the variance at this phase of the model, with cognitive flexibility being the most significant predictor. The results of this study built on previous research which investigated the importance of three cognitive processes to complex prospective memory; retrospective memory, inhibition and working memory (Kliegel et al., 2000). In this study, participants' performance on the complex PM task was related to performance on a sentence span test of working memory (Waters & Caplan, 1996), a test of retrospective memory for action sequences (Cohen, 1981, Martin & Schumann-Hengsteler, 1996) and the Stroop test of inhibitory control. Results indicated that none of these tests related significantly to the intention formation or intention retention phases. Inhibition and working memory were significantly related to the intention initiation and intention execution phases. Together, the results of these studies support an important role for executive functions in the successful prospective organisation of actions, as measured by complex prospective memory. The potential contributions of executive and non-executive functions to the stages of the process model of PM are summarised in Table 2.1.

Table 2-1: Potential contributions of executive and non-executive functions to the process model of PM

<table>
<thead>
<tr>
<th>Phase of Process Model</th>
<th>Executive/ Non-executive Process Involved</th>
<th>Contribution to Prospective Remembering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intention formation</td>
<td>Planning</td>
<td>Adequate plan sets up good PM cues highly associated with intended action.</td>
</tr>
<tr>
<td>Intention retention</td>
<td>Retrospective memory</td>
<td>Retrospective memory holds the content of the intended action and the PM cue associations over the delay period.</td>
</tr>
<tr>
<td>Intention initiation</td>
<td>Cognitive flexibility</td>
<td>Cognitive flexibility is required to switch attention from the ongoing activity to the prospective cue to recognise it when it occurs.</td>
</tr>
<tr>
<td></td>
<td>Inhibition</td>
<td>Inhibition required to inhibit attention to the ongoing activity and focus on the PM cue.</td>
</tr>
<tr>
<td>Intention execution</td>
<td>Cognitive flexibility</td>
<td>To implement the original plan, continually updating and modifying it as the situation demands.</td>
</tr>
<tr>
<td></td>
<td>Inhibition</td>
<td>Inhibition required to switch between tasks, inhibit attention to current task to switch to the next.</td>
</tr>
</tbody>
</table>
In sum, the most influential executive function at the 'intention formation' stage is planning and the most influential executive functions at the intention initiation and intention execution stages are cognitive flexibility and inhibitory control (Kliegel et al., 2002). The process model of prospective memory operates within a limited capacity space (McDaniel & Einstein, 2000) and is therefore related to working memory. The involvement of each of these executive functions in the prospective organisation of action is reviewed below.

2.4.2 Planning and the organisation of future behaviour

Planning can be conceptualised as separate from other intentional processes underlying multitask performance on the basis of its role in the formulation of intentions rather than the initiation or execution of intentions (Kliegel et al., 2000, 2002). Some patients with frontal lobe injury retain the ability to formulate a reasonable plan, but are subsequently unable to follow through and implement their plan successfully, suggesting planning is separable from the processes involved in the execution of intended actions (Shallice & Burgess, 1991). Planning and prospective memory are hypothesised to be separate but essential processes involved in performance on a real world multitask paradigm, in which patients with closed head injury and controls were asked to perform complex activities of daily living involving planning and preparing a complete meal (Fortin et al., 2002).

Planning has a uniquely important relationship with prospective memory which centres around the encoding and subsequent retrieval of intentions (Burgess, 1997). Planning an intended action influences the success of later prospective remembering; a well formed plan (i.e. a detailed plan) is more likely to generate a better retrieval context (with well set-up prospective cues) than an ill formed plan (Burgess and Shallice, 1997; Kliegel, McDaniel & Einstein, 2000; Mantyla, 1996). In a laboratory task participants who produced plans specific to target events outperformed participants who produced plans for general categories of target events (Ellis and Milne, 1996). The role of planning in habitual prospective remembering has been investigated; participants who had detailed where and when they would take a pill during the course of the day remembered to take the pill significantly better than participants who had only formed the intention to take a pill at some point during the day (Sheeran & Orbell, 1999).
Similarly, detailed planning is an important part of everyday prospective remembering (Gillholm, Ettema, Selart et al., 1999). Participants planned a prospective act using one of three levels of planning: (i) merely forming an intention to enact the PM task, (ii) specifying when and where the PM task would be enacted or (iii) detailing other activities to be carried out on the same day and incorporating the PM task into this plan. Participants who gave the most detailed plan were most successful at completing the task, followed by those who detailed when and where the PM task was to be enacted; supporting the hypothesis that planning an activity increases the likelihood that it will be performed (Gillholm et al., 1999). Gollwitzer (1999) stresses the importance of ‘pre-deciding’ how to implement a future goal, rather than just thinking about the goal; ‘implementation intentions’ specify ‘where, when and how’ an intention towards attaining a goal may be carried out (see Figure 2.5).

Figure 2-5: Planning and prospective memory

Gollwitzer (1999) stresses the importance of ‘pre-deciding’ how to implement a future goal, rather than just thinking about the goal. Consider an everyday example. On Monday morning I set out with 3 letters to post on my way to work. I arrived at work with the letters still in my bag. I realised this was because I had not made a detailed plan about where to post the letters; rather, I had just formed the intention to do so. On Tuesday morning I set off again, with the letters once again in my bag. Yet again I had formed no specific plan regarding where and when I planned to post the letters, other than ‘somewhere’ on my way to work. ‘How’ was in this case straightforward – put the letters into the letterbox. Fortunately I arrived at work with no letters in my bag. The only reason I was successful in this enterprise was because I happened to stop at a red light next to a post box, the presence of which cued my intention to post the letters, enabling me to successfully perform my intended action in the absence of a detailed plan.

The evidence discussed above indicates that the planning an individual engages in affects the nature and activation of the PM representation. It is likely that this will in turn affect whether prospective remembering occurs automatically or effortfully. Planning has a close relationship with the successful execution of prospective intentions.

2.4.3 Other executive functions involved in the organisation of future behaviour

A number of other executive functions are involved in the organisation of future behaviour; these include cognitive flexibility, inhibitory control, performance monitoring and working memory.
In experimental studies, inhibition and cognitive flexibility have been found to relate to prospective memory performance. Martin et al. (2003) used the Stroop colour-word task to assess inhibitory control and the Wisconsin Card Sorting Test to measure cognitive flexibility and found that performance on these tests predicted a great amount of variance in performance on a test of complex PM. Similarly Groot et al. (2002) found that performance on these two tests of executive function correlated with performance on event-based and time-based tests of prospective memory in both brain injured patients and controls, supporting the involvement of executive functions in all forms of prospective memory. Performance on these same two tests of executive function relates most strongly to the intention initiation phase of the process model of PM (Kliegel et al., 2002). For a delayed intention to be initiated cognitive flexibility is required to switch from the ongoing task to the prospective task. It is likely that inhibitory control is also required at this point to inhibit attention to the ongoing task, enabling attention to be switched to the prospective task. In multitask tests, which test an individual’s ability to organise future actions, cognitive flexibility can be measured by task switching behaviour. Measuring the number of tasks attempted by each participant helps to identify whether participants lack cognitive flexibility and perseverate, or whether they switch fluently between multiple tasks (Burgess et al., 2000; Kliegel et al., 2002; Shallice & Burgess, 1991).

Likewise monitoring the environment for external cues is incorporated into both the SAS model of the control of goal-directed action, and the process model of PM (Shallice & Burgess, 1996; Kliegel et al., 2000, respectively). In both models more salient cues (intention markers) result in more proficient prospective remembering (Brandimonte & Passolunghi, 1994). Monitoring one’s internally generated cues also forms a part of these frameworks, as is required in time-based prospective memory tasks. In addition, on-line monitoring is used to evaluate the success of completed actions and current relevance of previously planned actions. High levels of on-line monitoring are associated with better prospective memory performance in some (Cherry & LeCompte, 1999; Einstein & McDaniel, 1990, Maylor, 1998) but not all studies (Reese & Cherry, 2002). In patients with frontal lobe damage monitoring difficulties often manifest as confabulation (e.g., Burgess & Shallice, 1996b). In multitask paradigms, monitoring skills are measured by asking participants to recount what they have achieved during their performance and assessing how closely this matches the reality of what has been done. Frontal lobe patients show evidence of impaired monitoring ability (Burgess et al., 2000).
The role of working memory in the organisation of future behaviour is highlighted in both models. Working memory capacity limits the processing space available for the cognitive processing involved in the organisation of future behaviour. In the SAS model the implementation of a new schema (execution of the prospective act) takes place within the confines of a limited capacity special purpose working memory (Shallice & Burgess, 1996). Similarly, in the process model of PM working memory capacity is important at both the intention initiation and the intention execution phases, as a previously generated intention is activated into current or working memory (Graf & Uttl, 2001). Prospective memory correlates with working memory (Groot et al., 2002). Impairments in laboratory performance on prospective memory tests by older adults have been attributed to reduced processing capacity (Einstein et al., 1995; Maylor, 1993, 1996). Manipulations of working memory load influences PM performance in younger participants (e.g., Einstein et al., 2000). These studies provide evidence to support the claim that working memory capacity constrains PM.

One additional executive function deserves a mention. Fortin et al. (2002) speculate that strategic planning underlies successful performance on their ADL multitask. Martin et al (2003), in their regression analysis of executive function and prospective memory performance, demonstrated that non-executive factors (e.g., years of education), executive factors (planning, switching attention and mental flexibility) and age accounted for 77% variance in participants PM performance. They speculated that other non-executive factors such as motivation or other executive processes not measured, such as problem solving strategies, might account for the remaining variance (Martin et al., 2003). In studies where multiple prospective actions are to be performed, a relationship between prospective memory performance and strategic problem solving ability would seem to be quite plausible. Strategic rule use is viewed as an executive function in its own right (e.g., Zelazo & Frye, 1996; Zelazo & Muller, 2002).

### 2.4.4 Summary of executive functions and the organisation of future behaviour in adults

In sum, there is a great deal of evidence to support a role for executive functions in the prospective organisation of actions. Different executive functions are important at each stage of prospective remembering. Planning, cognitive flexibility, inhibitory control and possibly strategic rule use may play different roles in the organisation of future behaviour. Both models under discussion reserve an
important role for working memory. Executive functions are closely associated with the frontal lobes of the brain (e.g., Duncan et al., 1996; Fuster, 1989; Tranel, Anderson & Benton, 1994). Compatible with this observation, there is strong evidence to support frontal lobe involvement in the organisation of future goal-directed action and in prospective memory. This evidence is reviewed below.

### 2.5 The neuroanatomical correlates of the organisation of future action

Patients who have difficulty organising their future behaviour in everyday life have frontal lobe pathology in common (e.g., Bechara et al., 2000; Burgess, 1997; Duncan et al., 1995; Eslinger & Damasio, 1985; Fortin et al., 2002; Goldstein et al. 1993; Shallice & Burgess, 1991). The realisation of delayed intentions is sub-served by executive processes mediated by the prefrontal cortex (Bisiach, 1996; Burgess et al., 2000; Glisky, 1996; McDaniel et al., 1999; Stuss & Benson, 1987). Burgess et al. (2000) compared a group of neurological patients with a variety of cortical lesions to controls who had performed their Greenwich multitask test. Patients with pathology involving the prefrontal cortex failed to perform the multitask at an equivalent level to controls. They analysed the brain scans of patients to identify relationships between the anatomical location of the patients' lesion and the different aspects of multitask performance compromised. These results are summarised below, alongside evidence from other studies pertinent to the neuroanatomical basis of the organisation of future action. Figure 2.6 illustrates the neuroanatomical regions associated with the cognitive processes involved in the organisation of future behaviour.

[1] Prospective Memory

There is strong evidence that the brain region most involved in processing prospective intentions is the prefrontal cortex (Burgess, 2000; Burgess & Shallice, 1997; Burgess, Quayle & Frith, 2001; Leynes, Marsh, Hicks et al., 2003). In their analysis of the brain regions involved in multitasking, Burgess et al. (2000) found that the left ventromedial prefrontal cortex (Brodmann areas 8, 9 and especially 10) was specifically involved in aspects of task performance thought to contribute to prospective memory. This result supports evidence from a PET study in which regional cerebral blood flow (rCBF) increased in inferior frontal regions (BA 8, 9 and 47) and left superior frontal gyrus (BA 10) during an event-based prospective memory task (Yamadori, Okuda, Fujii et al., 1997). Another PET study has compared
activation patterns under prospective memory and control conditions (Okuda et al., 1998). Regions that were substantially more active during the prospective memory condition included the left frontal pole (BA 10), the right ventrolateral prefrontal cortex (BA 47), the right dorsolateral prefrontal cortex (BA 8 and 9) and medial aspects of the prefrontal region (medial BA 8). ERP studies of prospective memory also support involvement of the medial frontal region (West, Herndon & Ross-Munroe, 2000) and the right frontal region (Leynes, Marsh, Hicks et al., 2003).

Clearly there is a great deal of consistency in the brain regions most active in prospective memory. Interpretations of these activations are also broadly consistent. Memory for intended actions is maintained in the left frontal polar region BA 10 (Burgess et al., 2000, 2001; Burgess, Scott & Frith, 2003; Leynes et al. 2003; Okuda et al., 1998; Yamadori et al., 1997). It is possible that the right ventrolateral region BA 47 is also involved in both holding intentions (Burgess et al., 2000, Okuda et al., 1998) and mediating the retrieval of intentions (Leynes et al., 2003). Intention retrieval has also been ascribed to the medial frontal region BA 8 alongside an active role in intention execution (West et al., 2000). This retrieval and execution interpretation is compatible with the suggestion that the medial aspects of BA 8 are involved in dividing attention between working memory and the prospective task (Okuda et al., 1998). The prefrontal cortex mediates executive memory processes involved in working memory, such as selective attention and task management (Smith & Jonides, 1999; Smith, Geva, Jonides et al., 2001).

The role of BA 10 in prospective memory is potentially very interesting; in a PET study involving performance on a PM task participants performed an ongoing task under three conditions (Burgess et al., 2001). In a baseline condition ongoing task performance was monitored, in an 'expectation' condition participants had received PM task instructions, but no PM cues appeared, and in a 'test' condition participants received PM instructions and PM cues appeared. In the expectation condition, relative to the baseline condition, rCBF in BA 10 increased as did rCBF in the right dorsolateral prefrontal cortex (RDLPFC); in the test condition (in which the prospective intention is realised), rCBF in BA 10 did not increase further, and rCBF in the RDLPFC decreased. From this the authors concluded that BA 10 may be more involved with the maintenance rather than the activation of delayed intentions. Further investigations of the role of BA 10 in the maintenance of delayed intentions have
revealed a possible anatomical dissociation between medial and lateral aspects of the ventromedial prefrontal cortex (Burgess et al., 2003). Medial areas of BA 10 show rCBF decreases in PM tasks in which PM cues are expected, encountered and acted upon, whilst conversely lateral aspects of BA 10 show corresponding increases in rCBF. This finding might support a specific role for BA 10 in the voluntary switching of attention from the ongoing task to the prospective task, a situation in which the tension between maintaining an intention whilst performing an ongoing task may be resolved by the ‘dual function’ of BA 10. It is possible that medial aspects of BA 10 might act to maintain attention on external stimuli (the ongoing task), and/or to suppress internally generated thoughts; whilst lateral aspects of BA 10 act to maintain internally generated thoughts (one’s intentions) leading to the switch of attention from the ongoing task to the PM task (Burgess, Scott & Frith, 2003).

Planning

Lateral aspects of the right frontal lobe (Brodmann areas 8, 9 & 46) are involved in planning during multitask performance. This fits with previous investigations which support a key role for the dorsolateral prefrontal cortex in planning on tasks such as a verbal fluency task (Cardesbak, Demonet, Vallier et al., 1996); a spatial working memory task (Miotto, Bullock, Polkey et al., 1996), a multitask strategic performance measure (Levine, Stuss, Milberg et al., 1998b) and a real-life architectural planning task (Goel & Grafman, 2000). These regions of the dorsolateral prefrontal cortex are also associated with working memory performance (D’Esposito, Detre, Alsop et al., 1995; Levy & Goldman-Rakic, 2000; Smith, Jonides & Koenpe, 1996).

Retrospective Memory

Areas of the left anterior cingulate and surrounding paraventricular white matter and the posterior cingulate (BA 23 & 24) were found to support retrospective mnemonic functions in multitasking, as measured by rule learning and rule memory. Multiple studies link these regions to retrospective memory including functional imaging studies (e.g., Grasby, Frith, Friston et al., 1993; Nyberg, McIntosh, Cabeza et al., 1996), patient studies (e.g., Mattioli, Grassi, Perani et al., 1996) and animal studies (e.g., Bussey, Everitt & Robbins, 1997a; Bussey, Muir, Everitt et al., 1997b). There may even be evidence of a dissociation of the roles of these regions in rule learning; the posterior cingulate may be more involved in memory for rules after a delay period (Bussey et al., 1997b).
In sum, research indicates that the prefrontal cortex is a particularly important region for the prospective organisation of goal-directed behaviour. Brodmann’s area 10 in particular has consistently been activated in lesion studies, PET studies and ERP studies; this region is believed to have an important role in maintaining information about intentions and switching attention from current to prospective activities. Other regions of the right dorsolateral prefrontal cortex are activated in studies where prospective demands are complex (such as multitasking) including BA 8, 9 and 46, which are known to be important regions involved in planning and working memory. The anterior and posterior cingulate regions are active in the retrospective memory phases of multitasking, where they are believed to fulfil a function of encoding and remembering information about task rules. This evidence is summarised in Figure 2.6 below.
**Figure 2-6: Neuroanatomical correlates of the organisation of future behaviour**

**BA 8 & 9: Prospective Memory Performance**
- Lesion studies (Burgess et al., 2000)
- PET Studies (Burgess et al., 2001; Yamadori et al., 1997; Okuda et al., 1998)
- ERP studies (Leynes et al., 2003)

**BA 10: Prospective Memory Delayed Intentions**
- Lesion studies (Burgess et al., 2000)
- PET studies (Burgess et al., 2001; Yamadori et al., 1997; Okuda et al., 1998)

**Lateral BA 10**
- Maintain internal intention to switch to prospective action (Burgess et al., 2003)

**Medial BA 10**
- Maintain attention on ongoing task, suppress internally generated thoughts (Burgess et al., 2003)

**BA 8, 9 & 46: Planning & Working Memory**
- Plan in PM (Burgess et al., 2000, Levine et al., 1998)
- Verbal plan (Cardesbak et al., 1996)
- Spatial plan (Miotto et al., 1996)
- Real life plan (Goel & Graffman, 2000)
- WM (D’Esposito et al., 1995, Levy & Goldman-Rakic, 2000, Smith et al., 1996)

**BA 24 & 24: Retrospective Memory**
- Lesion studies (Burgess et al., 2000, Mattioli et al., 1996)
- fMRI studies (Grasby et al., 1993, Nyberg et al., 1996)
- Animal studies (Bussey et al., 1997a, 1997b)

**Anterior Cingulate BA 24**
- Role in rule learning in multitasking

**Posterior Cingulate BA 23**
- Role in rule memory after a delay (Bussey et al., 1997a)
2.6 Summary of adult research

A substantial amount of research has investigated adults' ability to organise their future behaviour. A number of psychological processes are involved in the prospective organisation of action including prospective memory, aspects of retrospective memory and executive functions. Whilst all these processes work together to enable the organisation of future behaviour, prospective memory has been identified as being of particular importance. Prospective memory is the process involved in the creation, maintenance and activation of delayed intentions and has a vital role in the organisation of future behaviour. It is this ability which appears to be damaged in frontal lobe patients who have significant difficulty organising their future activities, which can lead to a loss of independence.

Prospective memory is distinct in its use of memory cues which are important for both encoding and retrieving 'to-be-remembered' intentions. Two models of the prospective organisation of action have been considered; both attach great importance to 'prospective cues' (McDaniel & Einstein, 2000; Kliegel et al., 2002) or 'intention markers' (Shallice & Burgess, 1991, 1996). In both models, cue information is processed within the confines of a limited capacity attentional system; processing can occur automatically or voluntarily depending on the interaction between cue information and attentional resources. Once a goal has been identified, the prospective organisation of action occurs in four distinct stages in which (1) the intention to act is generated, (2) this intention is delayed, necessitating that it be retained over a period of time, (3) the intention to act is remembered and initiated at an appropriate time, and (4) the intended act is executed successfully. Prospective remembering across these four stages interacts with other cognitive processes including retrospective memory and executive processes, both of which contribute to the organisation of prospective goal-directed action. The ability to create, maintain and execute delayed intentions is mediated primarily by the frontal regions of the brain, reflecting the high-level cognitive processing involved in organising future actions.

Multitasking has proved a valuable methodology in assessing the organisation of future behaviour in adult populations. Multitask paradigms place demands on prospective and retrospective memory and executive functions. Burgess et al. (2000) developed a multitask paradigm which enabled them to measure retrospective, prospective and executive components of performance separately. Multitask
paradigms successfully distinguish patients who have difficulties organising their future behaviour from those who do not, indicating that these tests are strongly related to functioning in everyday life.
Chapter 3: The organisation of future behaviour in children

The organisation of ‘future behaviour’ in children

The central nature of ‘future-oriented’ abilities has also been recognised as an important facet of cognition in children (Haith, 1994). Various fields within developmental psychology have attempted to qualify both the nature of these future-oriented processes and their development. Whilst research into the organisation of future behaviour in adults is now fairly well established, focused research with children is somewhat more sparse. As a result, no specific cognitive models of the organisation of future behaviour in childhood have been developed. Therefore we shall focus our investigation according to the cognitive processes hypothesised to underlie the organisation of future behaviour in adults. We are aware that this approach of scaling down from ‘end state’ adult models has its limitations and remain alert to the possibility that the processes underlying the organisation of future action may change across development.

This chapter is structured in a similar format to the adult literature reviewed previously. We begin by considering evidence that supports deficits in the organisation of future behaviour in child neuropsychological patients with frontal lobe damage and developmental disorders. We then discuss two studies that have investigated multitasking in typically developing children. Following this, the development of the skills involved in organisation of future behaviour is considered under a different name, as it has been conceptualised in developmental research: as ‘future-oriented processes.’ We then review the growing body of research into prospective memory in children and the more extensive
field investigating the development of executive functions in childhood. Finally, evidence for the protracted development of the prefrontal cortex across childhood is reviewed, providing a biological basis for the continued development of the skills mediated by this region. The focus of this chapter is on how these underlying processes develop.

3.1 Child neuropsychological research

In this section we consider research that has investigated whether children with brain injuries or developmental disorders exhibit deficits in their ability to organise future behaviour. Adult neuropsychological research has contributed a great deal to our understanding of the cognitive processes underlying the organisation of future behaviour. Adult frontal lobe patients exhibit difficulties organising future actions and evidence from single case studies suggests that children with frontal lobe injuries exhibit similar difficulties. In adult research the key psychological process underlying the organisation of future behaviour has been identified as prospective memory (PM). Although PM has not been investigated in children with frontal lobe damage, it has been investigated in children with acquired traumatic brain injuries (TBI) and in children with developmental disorders. There is evidence that prospective memory is impaired in both these clinical groups. This evidence is discussed below.

3.1.1 Child frontal lobe patients

Children who sustain frontal lobe injury early in childhood exhibit similar deficits in the prospective organisation of action to those observed in patients whose injury is acquired in adulthood (e.g., Damasio, 1994; Damasio & Anderson, 1993; Grattan & Esiinger, 1991). Single case studies report children who have significant difficulties structuring and organising future actions. JP, who sustained congenital bilateral frontal lobe injury, is reported to have ‘an inability to perform more than one task at a time’ (e.g., Ackerly, 1964). Other case studies of children with frontal lobe damage have been reported, all of whom display difficulties in organising information, in gaining knowledge and in subsequently acting upon this knowledge (Grattan & Esiinger, 1991; Mateer & Williams, 1991).

Two patients reported have been by Anderson, Damasio, Tranel and Damasio (2000); both sustained discrete prefrontal cortex (PFC) damage in early childhood, prior to 16 months of age. Like the adult
patients reported by Shallice and Burgess (1991), these patients exhibited gross problems in everyday functioning, relative to largely intact intellectual functioning. Descriptions of the two cases reveal individuals whose everyday lives are characterised by failures of future-oriented, goal-directed behaviour. Patient FD sustained a traumatic brain injury aged 15 months. Disruptive behaviour patterns began to emerge around 3-years of age and grew subsequently more pronounced. At school observations of FD include the fact that she “…rarely completed assignments unless someone worked with her and kept her on task” (Anderson et al., 2000: page 284). As a teenager FD was placed in treatment facilities where her behaviour was characterised by “…rules violations… failure to progress toward treatment goals…” and petty crime using “poorly thought out” strategies (Anderson et al., 2000: pages 284-5). In her adult life FD is chaotic, unfocused and disorganised and she remains “…unable to articulate any plans for the future…” (Anderson et al., 2000: page 285). The second patient discussed is ML who had a frontal malignancy resected at the age of 3 months. Aged 5 years he had “…difficulty adjusting to new situations… [and needed]… frequent reminders to stay on task and to complete assignments” (Anderson et al., 2000: page 286). Once ML left school “his behaviour problems became more apparent…likely due to the loss of daily structure provided by the school setting” (Anderson et al., 2000: page 286). As an adult ML’s “failure to consider future consequences of his actions was a stable feature of [his] daily behaviour. He appeared to engage in virtually no adaptive planning for the future” (Anderson et al., 2000: page 287). For example, ML was “…not able to manage his monetary resources; he would quickly spend all available funds with no consideration for his financial obligations. He repeatedly bought items on credit and then failed to make payments” (Anderson et al., 2000: page 286). ML was “…unable to generate any feasible response to questions regarding future employment or personal goals” (Anderson et al., 2000: page 287). The descriptions of these two patients give some insight into how difficult it must be to live life without having future goals to aspire to, or the means to organise oneself towards achieving those goals that are held.

There is evidence to suggest that adults with frontal lobe injury can exhibit a selective deficit in the ability to execute delayed intentions. These adult patients can identify goals and even form reasonable plans to achieve these goals, but somehow fail to apply this knowledge in their everyday lives (Shallice & Burgess, 1991). They often perform well on tests traditionally sensitive to frontal lobe functioning, such as the Tower of London planning test, but are distinguished by their performance on less
structured tests such as multitask paradigms (Burgess, 2000; Shallice & Burgess, 1991). To the best of our knowledge no children with damage confined to frontal lobes have been reported who demonstrate a similar specific impairment in the ability to organise prospective actions in everyday life, in the face of relatively intact performance on traditional empirical tests of executive function. We can find no published studies of multitask performance in children with discrete frontal lobe lesions. In the case studies reviewed above, all the children were reported to have impaired performance on at least some traditional tests of executive function. This finding is in accordance with adult research, which suggests that a lot of executive control is involved in prospective remembering (Kliegel et al., 2000, 2002, Martin et al., 2003).1

In sum, the evidence from children with frontal lobe damage supports the involvement of the frontal regions in the organisation of future actions in childhood as well as in adulthood. Frontal lobe brain injuries acquired in childhood appear to have a severe impact upon children’s ability to organise future actions in their day-to-day lives. Moreover reports of executive function deficits in these children support the involvement of executive functions in the organisation of future action. It remains unclear whether the ability to create and execute delayed intentions can be selectively impaired in children as it appears to be in adults. This question requires further research. Unfortunately none of these children were assessed using tests sensitive to the organisation of future actions (multitask paradigms) or more direct tests of prospective memory. More targeted investigations of the organisation of future action have focused on both prospective memory and multitasking in children with traumatic brain injuries and developmental disorders. These clinical studies will be reviewed here, whilst studies investigating multitasking in typically developing children will be reviewed in the section 3.2.

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1 Although performance on traditional tests of executive function in adults fails to predict all the variance in performance on tests of prospective memory (Kliegel et al., 2002). This leaves scope for the selective impairment of PM in the face of relatively ‘intact’ performance on traditional laboratory tests of executive functioning.
3.1.2 Children with traumatic brain injuries

To date, only two studies have investigated prospective memory functions in children with traumatic brain injury (McCauley & Levin, 2004; Ward, Schum, Dick & et al., 2004). Both these studies investigated prospective memory in groups of children with acquired brain injury. In contrast to the case studies discussed above, neither limited their sample to children with discrete frontal lobe damage.

Ward and colleagues (2004) investigated the impact of paediatric brain injury on everyday memory functioning in an interview study. They interviewed the parents of 13 children with traumatic brain injury to gain insights into how memory deficits following TBI impact upon children's day-to-day functioning. These authors opted for a qualitative information gathering approach, as it can be difficult to translate results obtained from empirical investigations of memory in terms of how they impact upon real life functioning. The interview focused on prospective memory and two types of retrospective memory (implicit and explicit). Deficits in retrospective explicit and prospective memory were reported across the sample and the severity of these deficits was not necessarily linked to the severity of injury. Minor deficits in implicit memory were only reported by the parents of two children. From 13 interviews conducted: 5 parents reported that their child had severe PM difficulties, 2 reported moderate PM difficulties and the remaining 5 reported only minor PM difficulties which did not interfere with everyday functioning (although the authors note that 1 of these 5 children may in fact have moderate rather than minor PM difficulties). Prospective memory failures in these children (who ranged from 9-16 years at time of interview) generally "... involved the children forgetting to take items to school, pass on messages, do chores and keep appointments at appropriate times or without reminders" (Ward et al., 2004, page 482). An example of a child with severe PM deficits is a 14-year old boy who sustained a mild TBI aged 8-years when his bicycle collided with a vehicle ('Patient 13'). This boy exhibits such severe PM deficits that his mother regularly calls him during the day to ensure he has not forgotten to switch off the stove, and stays on the line whilst he checks. In another case, a 13-year old boy sustained a TBI aged 4 when he fell 5 metres ('Patient 7'); this boy is frequently reported to leave lunch on the table when he leaves for school, to forget to hand over letters from school and to forget to pass on telephone messages. A 14-year old child with moderate PM difficulties is reported to forget to pass on information about school sports tournaments until days after he first received it ('Patient 12': sustained a mild TBI age 2 years in a pedestrian vehicle accident). This boy's parents report his
memory impairments to be his most significant difficulty, which impacts enormously on his day-to-day life.

McCauley and Levin (2004) report the first empirical study of prospective memory in children with TBI. In this study 3 groups of children performed a computerised event-based prospective memory task. Two groups of children with TBI (17 mild, 15 severe) were compared to an orthopaedic control group (N = 15, controls for time spent in hospital and out of education). The prospective memory task involved categorising words that appeared on a computer screen into one of two categories. The words were written in different colours and the PM task involved reporting blue words when they appeared on the screen. The onset of the PM task was delayed by 10-15 minutes after the instructions had been given; during which time participants performed an intervening task in which only black words appeared on the screen. Many children with TBI failed to self-initiate a response to blue words when they began to appear during the category judgement task compared to orthopaedic controls. After a set period of time all participants were reminded of the PM task, after which children with mild TBI improved their PM response rates (as did children in the Orthopaedic control group) but children with severe TBI continued to show significant deficits in PM performance. In this study a relationship was observed between severity of TBI and severity of PM deficit (McCauley & Levin, 2004). Furthermore, performance on the ongoing task suffered as a result of the PM task in all groups (reaction times to make category decisions were longer for PM stimuli). This indicates that children’s prospective remembering, like adults, operates within a limited capacity space where prospective demands can impact upon performance on the ongoing task.

Memory deficits are the most commonly reported cognitive impairment following TBI (Levin & Eisenberg, 1979). It is clear from the studies reviewed above that prospective memory deficits in childhood can be profoundly disabling, disrupting educational and social development and causing great distress to the families and children affected. In adulthood, prospective memory impairments can impact upon adults’ ability to live independently (Graf & Uttl, 2001). It is possible that children with severe prospective memory impairments may fail to become independent of their parents as they mature (Ward et al., 2004). Therefore, early acquired injuries may be more impairing than those acquired in adulthood as children fail to develop abilities and functions as their typically developing
peers do (e.g., Eslinger, Grattan, Damasio et al., 1992; Marlowe, 1992; Mateer & Williams, 1991; Price, Daffner, Stowe et al., 1990).

A multitask paradigm has been designed as part of a battery of tests administered to children with acquired brain injuries and developmental disorders. This Six Parts Test is one of the tests that comprises the Behavioural Assessment of the Dysexecutive Syndrome for Children (BADS-C; Emslie, Wilson, Burden et al., 2003). The equivalent test battery in adults was designed to capture the constellation of higher order executive deficits observed following frontal lobe brain injury where patients are observed to have difficulties planning and sequencing behaviours, changing cognitive set, co-ordinating multiple activities and coping with novel situations (BADS: Wilson, Alderman, Burgess et al., 1996). The BADS-C was developed to identify dysexecutive problems in children with traumatic brain injuries or developmental disorders. The multitask test of the BADS-C is modelled on the Six Elements Test introduced previously (Shallice & Burgess, 1991). In the Six Parts Test children must perform multiple subtasks under time and rule-based constraints. Emslie and colleagues (2003) administered the Six Parts Test to 3 children with TBI who had been referred for clinical assessment because of learning or behavioural difficulties, and 23 children with TBI who were participating in clinical follow up studies. Their results indicate that the 3 children with TBI who had been referred for assessment performed much more poorly on the Six Parts Test than the 23 follow up children with TBI. This poor performance was reflected in all tests comprising the BADS-C battery indicating that these 3 children had severe dysexecutive difficulties following their brain injuries. This is the first data to show that children with TBI can have difficulty performing a multitask test, more research with this clinical test is expected in future. Emslie and colleagues also administered the Six Parts Test to children with developmental disorders; the results of this investigation are outlined below.

3.1.3 Children with developmental disorders

A number of recent studies have investigated the organisation of future behaviour in children with developmental disorders. This research has been stimulated by the increasing recognition that the prospective organisation of future actions is necessary for successful independent living, and by the growing body of research into the cognitive processes underlying this ability. Executive functions play a role in the organisation of future actions, and executive functions are frequently impaired in children
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with developmental disorders (e.g., Pennington & Ozonoff, 1996; Geurts, Verte, Oosterlaan et al., 2004). Prospective memory is believed to be the key cognitive ability underlying the organisation of future action, and PM has recently been investigated in children with attention deficit hyperactivity disorder (ADHD). These studies are discussed below.

Emslie and colleagues (2003) administered the Six Parts Test to children with a variety of developmental disorders; like the children with TBI these children were divided into two groups, children who had been referred for behavioural problems or learning difficulties, and children who were participating in clinical follow up studies. In the referral group were 38 children with ADHD, 5 children with attention deficit disorder (ADD), 13 children with pervasive developmental disorder (PDD), two children with developmental co-ordination disorder (DCD) and 7 children with dyslexia. In the follow up group were 10 children with congenital adrenal hyperplasia (CAH) and 13 children with hypoglycaemia. These groups were also compared to 259 typically developing control children (who will be discussed in more detail in section 3.6 when we consider multitasking in typically developing children). Children with ADHD and PDD showed impaired performance on the Six Parts Test relative to children with ADD, dyslexia, CAH, hypoglycaemia and controls, the two children with DCD were unable to attempt the test. Children with ADHD were reported to have particular difficulty performing the Six Parts Test. ADHD has been the focus of four recent investigations, three of which have employed multitask paradigms to assess the organisation of future action in this clinical group. These studies have made progress in identifying what might contribute to the multitasking deficits observed in ADHD.

Clark and colleagues (Clark, Prior & Kinsella, 2000) also used a modified version of the Six Elements Test to investigate multitasking deficits in adolescents with ADHD relative to adolescents with clinical diagnoses of oppositional defiant disorder (ODD) and conduct disorder (CD), and typically developing controls. They report that adolescents with ADHD performed fewer subtasks than children in either control group, but that they were no more likely to break the rules governing task performance, which might have been anticipated if rule breaking can be attributed to poor inhibitory control. The authors concluded that multitasking deficits in ADHD can be attributed to an impaired ability to strategically plan and organise information and to monitor ongoing performance, this interpretation was supported by the impaired performance of the children with ADHD on a separate strategy generation task (Clark et al.,
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2000). This result was recently replicated with school age children (Siklos & Kerns, 2004) in a study that substantially modified the Six Elements Test for use with younger children, creating a Children's Six Elements Test (C-SET). Once again children with ADHD had significant difficulty switching between subtasks, but did not break the ‘task order’ rule any more frequently than typically developing controls (the ‘task order’ rule was also colour coded in this multitask paradigm). This ability to avoid breaking the rules suggests that multitask performance deficits in children with ADHD represent high level impairments in which children have difficulties planning and monitoring their own performance. This planning deficit was explored by Kliegel & Kerber (in prep.), who tested children with ADHD and typically developing controls on a computerised multitask paradigm which is also based upon the Six Elements Test (Kliegel & Martin, 2003). They asked participants to form a verbal plan of how they would attempt 4 subtasks in 5 minutes obeying a task order rule. They report that children with ADHD were poorer at forming strategic plans than controls. During performance children with ADHD performed just as many subtasks as typically developing controls but made significantly more performance errors; thus performing as many subtasks as controls appears to have been at the expense of accurate performance, indicative of a trade-off in attentional resources. Finally Kerns and Price (2001) investigated time-based prospective memory in children with ADHD and found that they were impaired relative to typically developing controls. They attributed performance deficits to an impaired ability to generate appropriate strategies to monitor ongoing performance at appropriate times. This deficit in strategy generation in children with ADHD is congruent with the studies reported above. In sum, investigations of multitasking in children with developmental disorders have highlighted that multitasking deficits are apparent in some but not all developmental disorders. Moreover, multitasking has proved a successful methodology to assess the nature of the deficits experienced by children with ADHD, which involve impaired ability to form strategies, plan and self-monitor behaviour in everyday life.

Neuropsychological investigations of the organisation of future action in children have provided evidence that children with frontal lobe damage demonstrate impairments in this ability similar to adult frontal lobe patients. Furthermore, the ability to plan, sequence, and execute delayed intentions can also be severely compromised in children with TBI. Multitasking and prospective memory deficits have been the recent focus of research into some developmental disorders, where studies have identified
specific difficulties posed by multitasking for children with ADHD. The ability to prospectively organise goal-directed actions is vulnerable to impairment in brain injury and developmental disorders. What do we know about the normative development of this ability?

3.2 Multitasking in typically developing children

Two multitask paradigms have been developed and used to test children of different ages. One is the Six Parts Test of the BADS-C, designed as part of a clinical test battery to measure dysexecutive impairments in children with brain injuries and developmental disorders (Emslie et al., 2003). The other is a computerised multitask designed for children, the HEXE paradigm (Martin & Kliegel, 2003)

3.2.1 The Six Parts Test

The Six Parts Test consists of 6 subtasks, grouped into 3 task types (each pair is colour coded). The green tasks are simple arithmetic tasks (parts 1 and 2), the blue tasks are picture-naming tasks (parts 1 and 2) and the red tasks are object-sorting tasks (parts 1 and 2). All six parts are to be attempted within a 5-minute time limit, the order of task performance is constrained by a rule (don't do both parts of the same colour one after another). The six subtasks are laid out on the table in front of the child together with a countdown timer that remains in view throughout. The tester demonstrates each subtask to the child then explains the rules of the game providing 4 pieces of information. (1) They have 5 minutes to play the game. (2) They must do as much as they can of all six parts but that they don't have to finish one part before they go on to the next one as there is too much to do (3) They must make sure they have done at least something from each part. (4) They cannot do two parts of a task one after the other (you have to change colour each time). Performance is scored as the number of subtasks attempted and points are awarded where there is clear evidence that the child adopted a strategy for obeying the order rule and/or a strategy for ensuring that all six parts were attempted. Children are penalised each time they break the order rule.

The BADS-C was normed on a sample of 259 typically developing children aged 8-16 years. Although the results of this procedure have not been formally presented as a cross sectional study, patterns of performance change with increasing age can be identified in the age group norms presented in the
BADS-C manual. The children were a sample representative of the general population, drawn from schools across the socio-economic spectrum. Mean IQ was for the whole sample was estimated to be 99.8. The patterns of data in the BADS-C norms suggest that performance on the Six Parts Test improves steadily with increasing age. The greatest age differences in performance are seen between children who achieve lower scores. This greater variability across age groups at the lower end of the performance range is suitable for a clinical test where one might expect to assess more children who score at lower end of the scale.

3.2.2 The HEXE multitask paradigm

The second multitask paradigm to be developed for children is the computerised HEXE paradigm (Martin & Kliegel, 2003). This test was developed to assess complex prospective memory in children, and is a version of an adult computer task previously developed (Kliegel & Martin, 2000). This children's version is also modelled on the Six Elements Test, but has four rather than six subtasks consisting of two arithmetic subtasks and two picture naming subtasks. As in other multitask paradigms the order of subtask performance is constrained by a rule – you cannot perform both parts of a paired subtask one after the other. All four subtasks are represented on the computer screen and participants must click on a subtask to select it. The time is represented by a bar at the top of the screen which fills up as time passes. In order to make task administration as simple as possible, children respond ‘yes’ or ‘no’ to the stimuli on screen. For example in the arithmetic task the sum ‘2 + 3 = 5?’ appears and the children press ‘yes’ or ‘no’. The rules governing performance on the HEXE multitask are: (1) there are 5 minutes to play the game, (2) the child must do as much as they can of all 4 parts, (3) they don’t have time to finish all 4 parts and (4) they cannot do two parts of a task one after the other. Performance is measured as the number of subtasks attempted minus the number of times the task order rule is broken.

The HEXE multitask paradigm was administered to 115 children aged between 6-11 years. 20 children mean age 6.5 years, 25 children mean age 7.0 years, 24 children mean age 8.0 years, 24 children mean age 9.0 years and 22 children mean age 10.0 years. The results indicate that children attempt more subtasks as they grow older, these are detailed in Table 3.1.
Table 3-1: Results from Martin & Kliegel (2003) HEXE multitask paradigm performance by children

<table>
<thead>
<tr>
<th>No subtasks attempted</th>
<th>Age Group (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6-years (20)</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>2.35 (.67)</td>
</tr>
</tbody>
</table>

6 < 8, 9 & 10 years; 7-years < 8-years & 10-years.

To summarise, two paradigms have been designed to investigate multitasking in typically developing children. The results from each of these paradigms indicate that multitasking performance improves between 6-16 years of age. Performance on multitasking tests relies on a set of cognitive processes including prospective memory, retrospective memory and executive functions. In the sections that follow we review evidence to support the development of each of these underlying cognitive processes across this 6-16-year age range. However, first we shall consider an area of developmental psychology that has focused on the development of ‘future-oriented processes’ as these can be considered precursors to the cognitive skills underlying the organisation of future behaviour.

3.3 The development of ‘future-oriented processes’ in children

An area of developmental psychology that is relevant to our investigation of the development of future behaviour is the study of ‘future-oriented processes.’ These are defined as forward-looking cognitive processes that enable us to organise our behaviour around events to come (Haith, Benson, Roberts et al., 1994). Haith and colleagues coined the term “future-oriented processes” to represent an integrated set of cognitive processes oriented towards the future, incorporating such concepts as “intentionality, goal setting, prediction, set, expectation, preparation, anticipation, planning and feedforward computation” (Haith et al.; 1994: page 3). Future-oriented processes have been studied from a developmental perspective, although such research is relatively rare (Haith et al., 1994). Generally speaking, these processes have been studied in isolation of one another rather than being considered as an integrated set, which limits their applicability to situations in which multiple processes are required, such as the organisation of complex future goal-oriented behaviour. However, studies of future-oriented processes provide important evidence to support the development of abilities such as ‘anticipation’ and ‘intentionality;’ considered here as important precursors to the ability to organise
future behaviour. Finally, it is clear from the above definition that there is much overlap between future-oriented processes and executive functions.

The precursors of future-oriented processing emerge early in development (Benson, 1994). The earliest source of children's sensitivity to the future comes from experiencing routines by which family practices and the contexts of everyday life 'scaffold' infant's knowledge of the future (Friedman, 1990; Benson, 1994). Regular routines enable children to develop an expectation of 'what happens next' and eventually they learn to anticipate 'what will happen next' (Benson, 1994). Infants aged up to 36-months engage in a range of future-oriented behaviours (order and sequencing, routines, planning, expectation, understanding of time and problem-solving) and these behaviours have differential developmental trajectories with the greatest period of development between 12 and 30 months of age (Benson, 1994).

Expectations or anticipations are a necessary pre-requisite of planning ahead, with the latter enabling us to organise our behaviour around the future. To plan successfully one must be able to anticipate possible outcomes - "first we anticipate, then we plan: by anticipating that it might rain, I can then plan to pack my umbrella" (Atance, personal communication). The development of expectations in infancy has been studied using 'visual expectation paradigms' to demonstrate how children learn to expect and anticipate future events (e.g. Haith, 1994, 1997). In these paradigms infants process visually presented information and form expectations based upon patterns or sequences in the visual array. Investigations reveal a pattern of developmental change across the first year of life as infants are able to form expectations relating to the timing, space and content of visual events with increasing sophistication (Haith, 1994). By 12 months of age infants are able to disengage from an ongoing event in order to anticipate what comes next. This type of gaze-shift truly reflects expectation (Reznick, 1994). 'Violation of expectation' has also been investigated (see Baillargeon, 1995, for a review). In these paradigms infants look longer at visual events that violate physical laws such as solidity or cohesiveness of objects than at events which do not. In order to demonstrate an awareness that expectations have been violated – infants under 12-months-of-age are believed to have formed an expectation in the first place.
Intentions are also viewed as a necessary prerequisite of planning; an individual must intend to achieve a particular future state (the goal-state) in order to plan how to achieve that state. The development of intentionality in infancy has been studied using object search tasks in which an infant forms the intention to obtain a toy and then plans a suitable sequence of actions to obtain it. Studies of manual object search tasks support the development of intentionality prior to the fuller development of the ability to plan ahead. During the first year of life young infants' performance on direct search tasks becomes more 'intentional' and focused toward retrieving the desired object (Willatts, 1984, 1984). On more complex object retrieval tasks such as the 'towel-toy task', infants must perform a sequence of actions in order to retrieve a toy. By 9-months of age they can retrieve a toy on a two-step version of this task (Willatts, 1984, 1999), by 12-months they can successfully solve a three-step version, and by 18-months toddlers are able to generate and evaluate alternative strategies for solution (Willatts, 1993, 1997, 1999). Some researchers propose that to retrieve the toy the infant must plan a course of action. However, it is more likely that this type of paradigm does not require true planning into the future (i.e. planning in advance of action), but instead reflects an earlier stage in the development of planning abilities - 'planning in action' (Wellman, Fabricius & Sophian, 1985; Atance & O'Neill, 2001a). It is possible to use 'planning in action' to achieve success on tasks where there is only a single path towards the goal (Bauer, Schwade, Wewerka et al., 1999).

Studies of planning in pre-school children have investigated performance on tasks where the goal is more ambiguous, or where there are multiple possible routes to achieve the goal. Bauer et al. (1999) found that older 2-year-olds were unable to solve a 3-step construction task when the goal-state was not made available to them. Atance and O'Neill (2001a) investigated the performance of 3-year-olds on series of 1-step novel problem-solving tasks. They concluded that the pre-schoolers were not planning their solutions in advance but were 'planning in action' as infants do (Atance & O'Neill, 2001a; Wellman et al., 1985; Klahr, 1985). However, with appropriate paradigms and less complex problems, young pre-schoolers are able to demonstrate planning in advance of action, although these plans are vulnerable to disruption by problems with less clearly defined goals or with ambiguous ordering of the steps or subgoals to solution (e.g. Klahr & Robinson, 1981; Klahr, 1985; Bauer et al., 1999). For example, Klahr and Robinson (1981) used a modified version of the Tower of Hanoi task ("Monkey cans" task) to demonstrate that 5- and 6-year olds are able to 'look ahead' by up to 6 moves into the
future where the sub-goals are easily ordered. However, in equivalent problems where the sub-goal order is ambiguous (e.g., flat-ending monkey cans or the ‘dog-cat-mouse’ problem), even 6-year-olds had problems applying planning ahead of action and resorted to step-by-step planning in action (Klahr & Robinson, 1981; Klahr, 1985). Research evaluating planning in pre-schoolers has also assessed their ability to plan real-world events such as going to the seaside (e.g., Hudson & Fivush, 1991; Hudson, Fivush & Kubeli, 1992; Hudson, Shapiro & Sosa, 1995). These studies have shown that children develop ‘scripts’ for events in everyday life and that planning using these scripts is more advanced than planning in novel situations (Hudson et al., 1995). Therefore planning in advance of action on complex novel tasks or on delayed gratification paradigms appears towards the end of the preschool years. Children continue to develop their ability to organise their behaviour around the future by learning to plan ahead in situations where the goal-state and the steps necessary to achieve the goal are ambiguous, where multiple solutions are possible at each step, or where they must rely on feedback or prior knowledge to guide performance.

Infancy research suggests that children develop knowledge of the future through the sequencing of everyday events. Research with the pre-school population supports this notion, although the order in which children acquire this knowledge remains controversial. It is unclear whether preschoolers first associate activities that ‘go together’ before they develop knowledge of their sequential order (O’Connell & Gerard, 1985), or whether they learn to temporally order event representations as they develop them (Bauer & Mandler, 1990, 1992). The majority of studies of event-sequencing do not focus on the sequencing of future events (Atance & O’Neill, 2001a). However, Friedman (1990, 2002) demonstrated that 4-year-olds are able to sequence events that occur over the course of a day, but that they order their sequencing from the perspective of the beginning of the day, irrespective of the time of day at which they are tested. In contrast, 6-to-8 year olds can sequence future daily events from the perspective of the current time of day, and 10-year-olds are able to sequence annual events accurately (Friedman, 2002).

Studies of violation of expectation have also been investigated in the preschool years. These paradigms involve manual search for objects rather than simply measuring looking time (as in the infancy research). This change in methodology produces different results: despite knowing where the
object is hidden 2-year-olds fail to search in the correct place (e.g., Hood, Carey & Prasada, 2000; Hood, 1995). These results have prompted researchers to hypothesise that the 'looking-time' paradigms employed in infancy research require less executive control than the looking and reaching paradigms used in preschoolers research (e.g., Thelen & Smith, 1994; Munakata, McClelland, Johnson & Siegler, 1997). This indicates that children's ability to use expectations to guide behaviour develops over the preschool years, a development that is most likely related to the parallel development of inhibitory control (e.g., Diamond, 1990; Hughes, 1998).

Delayed gratification paradigms, in which children have to make a choice between receiving a materially inferior reward immediately or a materially superior reward later are believed to measure future-oriented 'prudence' (Lemmon & Moore, 2001). Performance on this type of task undergoes significant developmental change during the pre-school years. Three-year-olds find it difficult to make choices in favour of future interests over immediate interests, whilst 5-year-olds are able to delay gratification in favour of the greater future reward (Thompson, Baressi & Moore, 1997; Moore, Baressi & Thompson, 1998; Baressi, 2001).

### 3.3.1 Summary of the development of future-oriented processes in childhood

In summary, precursors of the future-oriented processing emerge in infancy and continue to develop throughout the pre-school years. Children become increasingly able to anticipate events, to form expectations of them, and to identify violations of these expectations. At first children perform best in familiar settings as their concept of the future is scaffolded by everyday routines. However, these abilities are extended to more novel settings during the preschool years. The evidence suggests it is likely that ‘true’ future-oriented processing, measured by planning in advance of action and by performance on delayed gratification paradigms, only appears towards the end of the pre-school years. Therefore the foundations for the successful organisation of future behaviour appear to be in place by the end of the pre-school years. It is about this age that research into prospective memory abilities in children begins.
3.4 Prospective memory in children

Prospective memory is likely to be a vital skill for independent living (Kliegel & Martin, 2003; Ward et al., 2004) and it is plausible that PM will develop in childhood as children become increasingly independent and able to manage their own lives. "Initially children's actions are structured around daily events in which they always participate – getting up, mealtime, a working parent's arrival home, going to bed and so forth. Prospective remembering becomes a necessity when children have the freedom and the responsibility to choose between various actions – delivering a message from home to school, or vice versa, feeding the cat, stopping at the store and so on" (Meacham & Colombo, 1980, page 301). In adulthood, prospective memory has been identified as the key cognitive process underlying the organisation of future behaviour. Current models predict that adult prospective remembering operates within a limited capacity system and progresses through a number of stages, being processed either automatically or effortfully depending on a number of parameters. Parameters influencing successful prospective remembering include PM cue distinctiveness and association with the intended action, level of involvement in the ongoing/to-be-interrupted task and personal motivations surrounding the intended act. In evaluating PM in children, the primary questions concern whether there is evidence that children have prospective memory, when and how this develops and whether it is subject to the same or different parameters as adult prospective memory. Only a handful of studies of PM in children have been conducted and research into this area remains largely fragmented as different types of PM have been investigated via a variety of paradigms. We shall review these studies and then return to the primary questions outlined above.

3.4.1 Studies of prospective memory in children

Winograd (1988) has suggested that PM is such a vitally important skill that “…prospective remembering might be expected to manifest itself early in development because it is a means to an end. If one remembers to perform an activity one is rewarded” (Winograd, 1988: page 351). A number of studies support the presence of prospective remembering in very young pre-school children. In a naturalistic study of event-based PM, pre-school children aged 2, 3 and 4-years were given ‘deliberate reminding tasks’ by caregivers in the context of day-to-day activities (Somerville, Wellman & Cultice, 1983). PM tasks generally involved reminding the caregiver to perform an action and varied across
length of delay, short (5-10 minutes), long (hours/overnight) and level of interest to the child (low versus high). An example of a high-interest, long-delay task is ‘remind me to buy candy when we go to the store tomorrow’ whilst a low-interest, short-delay task might be ‘remind me to bring in the laundry before lunch.’ Caregivers administered the tasks over a two-week period and recorded responses in a structured diary format, noting whether children spontaneously responded to the PM cue (e.g. entering the store), or whether they needed to be guided by increasingly specific visual (stand near the candy) or verbal (is there something special we should remember to buy today?) prompting to recall the intended action. Children of all ages performed very well on some of the tasks set. Level of interest (thus motivation) had the greatest impact on performance and length of delay has a lesser impact: high-interest, short-delay tasks were performed an average of 73% of the time compared to low-interest, long-delay tasks which were performed on average only 17% of the time. No age-related differences in performance were found; a result that surprised the researchers involved. None of the age groups were significantly different from one another in terms of spontaneously remembering to perform the PM task, or in terms of the level of prompting required to perform the PM task, as children of all ages benefited equally from the use of prompts. Nor were there any age-differences in the number of children who had completely forgotten the PM task (which was very low). One explanation for this lack of age-differences in performance could be the involvement of the caregivers in task selection, which may have biased tasks selected for each child to be particularly motivating or not at all interesting, resulting in inflated positive or negative performance. Nonetheless, this study points towards three important findings. First, children as young as two-years-old are able to prospectively remember intended actions in response to event-based cues in naturalistic settings, indicating that prospective memory skills may indeed be present in very young children. Second, naturalistic settings may scaffold and support prospective remembering in children, mirroring studies of older adults whose performance on prospective memory tasks in everyday contexts is superior to performance in laboratory studies (e.g., Titov & Knight, 2001). Third, motivations surrounding the intended act may influence children’s successful prospective remembering as well as adults prospective remembering (Winograd, 1988). Indeed it is possible that in this study the influence of naturalistic context and motivation acted upon prospective memory performance to such a degree that age-related differences were obscured.
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Studies of children's 'time-based' prospective remembering provide further support for these findings. Comparing PM performance in home versus laboratory settings, Ceci and colleagues (Ceci & Bronfenbrenner, 1985; Ceci, Baker & Bronfenbrenner, 1988) gave 10 and 14-year old children the task of remembering to remove cupcakes from the oven after a delay of thirty minutes, during which time the children played a popular video game. Results showed that in a familiar home setting, even 10-year-old children adopted 'adult-like' time-checking strategies that enabled them to perform the PM task well. By contrast both 10- and 14-year-old children's laboratory performance on the PM task was less efficient, providing support for the idea that familiar settings scaffold children's prospective remembering. Furthermore the presence of gender differences in performance indicate that the nature or perceived importance of the PM task itself might influence performance (Ceci et al., 1988). Boys adopted an adult-like strategy for a traditional male sex-typed PM task (charging a motorcycle battery) but failed to do so for a potentially less interesting or motivating traditional female sex-typed PM task (removing cupcakes from the oven).

In a recent laboratory based study of time-based PM, 7-12 year old children played a computer driving game called the 'CyberCruiser' (Kerns, 2000). The ongoing task was an absorbing driving task during which the children had to dodge other vehicles and navigate their way along roads to earn points. The embedded PM task was to re-fuel the car, re-fuelling could only be done when the tank was ¼ empty, the children could monitor the fuel level by pressing a button which revealed the fuel gauge for 2 seconds. The task was performed for 5 minutes, and the tank needed re-fuelling five times. Each time a child ran out of fuel, they lost all the points they had earned, but continued to play the game until the end of 5 minutes. 7-year olds ran out of fuel significantly more often than 8-10 year old children, 11 and 12-year old children ran out of fuel very seldom. These results support the development of time-based PM in children age 7-12 years. Time-based PM may develop later than event-based PM; time-based cues are internally generated, such as the internal temporal monitoring hypothesis put forward by Ceci and colleagues (Ceci & Bronfenbrenner, 1985; Ceci et al., 1988) to explain clock-checking performance on their time-based 'cup-cake' PM task. Older adults find time-based PM more difficult than event-based PM, and children's concept of time develops from infancy through childhood (Friedman, 1990, 2002).
Nigro, Sense, Natullo and Sergi (2002) directly compared event-based and time-based prospective memory performance in children aged between 7-11 years. In their paradigm the child sat in a room solving mathematical problems for a period of 15 minutes. In the event-based condition, a confederate who was present at the beginning of the session left the room; the experimenter told the child that he had forgotten to pass on an important message to the confederate and asked the child to remind him to do so when the confederate returned. In the time-based condition the experimenter asked the child to remind him to make an important phone call after a set length of time; the child could refer to a digital clock placed behind him or her. Children were more successful at performing the event-based PM task than they were at performing the time-based PM task, confirming that event-based PM is easier for children as it is for adults. Supporting Ceci et al. (1988) and Kerns (2000) the time checking strategy adopted by children did not differ as a function of age (Nigro et al., 2002).

Somerville et al., (1983) found evidence that increasingly specific external cues aided PM performance, although they didn’t find evidence of age differences in this cue use across the 2-4-year age range they studied. Adult studies of PM indicate that external cues aid prospective remembering more than internally generated cues (e.g., West, 1988; West & Craik, 1999; Einstein & McDaniel, 1990) and this distinction is incorporated into McDaniel and Einstein’s (2000) model of PM, where external cues are more easily recognised, hence more likely to lead to successful prospective remembering. A number of studies provide evidence of external cue use facilitating children’s PM performance (Beal, 1985, 1988; Kreutzner, Leonard & Flavell, 1975; Meacham & Dumitru, 1976; Meacham & Colombo, 1980). Kreutzner et al (1975) conducted in depth interviews assessing children’s memory practices and identified that children as young as 5-years of age make use of external cues to aid their memory (e.g., putting skates by the door). Placing a PM cue in a salient or prominent place is comparable to adult strategy use, indicating that children may operate using similar mnemonic systems that respond well to salient cues. In a laboratory paradigm both 6 and 8-year old children were shown to benefit from using an external cue to remember a prospective act in an event-based a PM task (Meacham & Colombo, 1980). At the beginning of the test session children were told to remind the experimenter to open a ‘surprise box’ at the end. The box was then placed out of sight and the child played a card game with the experimenter. Half the children were given no cue and half had a clown placed on the table in front of them with the explanation that the clown would help them to remember to open the box. Children in
both age groups benefited from the external retrieval cue, replicating the results of an earlier study (Meacham & Dumitru, 1976). In this earlier study the 8-year olds out-performed 6-year olds despite the external cue (Meacham & Dumitru, 1976), in the later study no age group differences were found. This was attributed to the event-based task being more straightforward and motivating to children of both ages (Meacham & Colombo, 1980).

Beal (1985, 1988) compared strategy use of 3-5 versus 7-9 year old children on laboratory object retrieval tasks. Children were asked to indicate the best place to position a marker on a cup containing a hidden object, which would enable them to retrieve it later. Results indicated that 3-5 year old performed this task at chance levels with at least half the children unaware that a visible marker would be most beneficial, however 7-9 year olds were able to employ this strategy well. This laboratory task seems to fit well with studies reviewed above where laboratory settings prove more challenging than familiar everyday settings. However, the same research team investigated children's strategy use in an everyday context (returning a card to the experimenter at nap time during the nursery day) and found that young 3-5 year old children demonstrated equally little awareness of what constitutes an efficient strategy in this real-life task too (Beal, 1988). The 3-5 year old children failed to identify the most informative potential reminders (PM cues), over-estimated how informative these reminders would be and failed to use PM cues consistently without prompting (Beal, 1988). This led the conclusion that younger children do not “...recognise the need for a specialised association between the reminder and the target.” (1988, page 368). This conclusion fits with the findings of Kreutzner at al (1975) and Meacham and Colombo (1980), indicating that children's ability to select appropriate prospective cues (intention markers) develops across the 3-9-year period.

Passolunghi, Brandimonte and Cornoldi (1995) investigated children's ability to form an association between the PM cue and the to-be-performed action by manipulating the strength of association between the PM cue and the to-be-performed action. Their PM task was an adaptation of Einstein and McDaniel's (1990) computer based PM task. Children were required to read aloud words as they appeared on the screen as quickly and accurately as they could, when the PM cue appeared (the word 'boat') children were to press the space bar as fast as possible. To manipulate the strength of association between the PM cue and the to-be-performed act, 7 year old children either practised
pressing the space bar in the absence of the PM cue (low association condition) or in response to the word 'boat' on the screen (high association condition). This association manipulation benefited 7-year old children's PM performance. In a second manipulation, these authors investigated the effects of encoding modality on PM performance, as in adults the way in which the PM cue is initially encoded can influence the success of prospective remembering (Brandimonte & Passolunghi, 1994). Three different encoding modalities were investigated, and these differentially affected the PM performance of 7 and 10-year old children. 7-year old children's PM was enhanced by visually rather than verbally encoded PM cues whilst 10-year old children's was equally good under both conditions. This result may mirror similar findings in research into working memory which suggests that 5-year old children store visually presented information in the visual spatial sketchpad whilst 10-year old children re-code visual stimuli into verbal representations (Hitch, Woodin & Baker, 1989). Older children's performance was facilitated by motoric encoding of the PM cue (i.e. practising pressing the spacebar once when the word 'boat' was presented auditorily). The authors propose that motoric encoding requires the integration of the PM cue and the to-be-performed action, and that these integrative processes are developed in 10-year old children, whilst younger children in whom they are less developed need additional help (as in the cue association manipulation).

In a more recent study Guajardo and Best (2000) assessed pre-schoolers (3 versus 5 year olds) use of external PM cues in a laboratory setting. They used a computer PM task adapted from Einstein and McDaniel (1990) in which they attempted to control two of the task parameters discussed above, strategy use and motivational influences on PM performance. In the ongoing computer task the child was presented with sets of picture cards for subsequent recall, the embedded PM task was to press the space bar each time the target card appeared. The external cue was a card the child had selected (from a choice of three) to aid PM performance; this was counterbalanced with a no external cue condition. Motivation was controlled in an incentive condition (reward prior to performance with the instruction that another reward would be given each time the child remembered to press the space bar at the PM cue) versus a no incentive condition. Results indicated that even 3 year olds performed this PM task above chance, although significantly less proficiently than 5 year olds whose performance was close to ceiling. Neither age group was affected by the presence or absence of an external PM cue, or by added incentive to perform the PM task. However, post-hoc analyses revealed qualitative
differences in PM strategy use: 48% of 5-year-olds reported using a strategy to help them remember the PM task compared to only 28% of 3-year-olds. The 3-year olds who reported using a strategy tended to use an external cue to guide performance ('I looked at the picture') whereas the 5-year olds were equally likely to employ an internal or external cue. Further analysis showed that children who had adopted a strategic approach performed the PM task better than those who had not, irrespective of age. The results suggest that PM strategy use is not fully formed by 5-years of age, in line with previous studies (Beal, 1985, 1988; Kreutzner et al., 1975; Meacham & Colombo, 1980; Passolunghi et al., 1995). Guajardo and Best (2000) did not find that manipulating motivation influenced PM performance on their laboratory task. It is possible that motivation may have greater influence on real life prospective remembering.

A further aspect of PM that has been well researched in the adult literature is switching attention from the ongoing task to the PM task. Two of the studies reviewed above provide support within a empirical PM paradigm that children are able to switch attention from the ongoing task to the PM task (Guajardo & Best, 2000; Passolunghi et al., 1995). In a study designed specifically to investigate switching in PM, Kvavilashvili and colleagues (Kvavilashvili, Messer & Ebdon, 2001) investigated the performance of 4, 5 and 7-year-old children on an event-based PM task during which ongoing task performance was interrupted, or not, by the PM cue. The ongoing task was a card-naming task and the children were given a cover story about helping a mole that couldn’t see very well to name the pictures. The embedded PM task was to hide any animal picture in a box behind the child, as the mole was afraid of other animals. Task interruption was manipulated by the PM cue (animal card) occurring halfway through a deck of cards (task interruption), or as the final card in the deck (no interruption). Children of all ages performed the PM task significantly better on the no interruption condition, under which the percentage of children who recalled the PM task improved by an average of 50% across all ages. The authors report small but significant effects of age on PM performance, with the greatest differences being between 4 versus 7-year olds. These age effects are found for both the interruption condition (% of children who remember all PM trials): 4 years (15%), 5 years (25%) and 7 years (55%); and for the no interruption condition (% of children who remember all PM trials): 4 years (60%), 5 years (75%) and 7 years (95%). Post performance, the authors investigated why some children had completely failed to act upon presentation of the PM cue by prompting them with a series of increasingly specific prompts.
regarding the relation between the PM cue and the PM task. Very few children had forgotten the task completely, but 4 and 5-year-old children required more specific prompts than 7-year-old children did. This study suggests that older children may be more proficient both at noticing the PM cue in the first instance, and at forming an association between the PM cue and the intended action, a result which is in keeping with previous findings (Beal, 1985, 1988; Guarjardo & Best, 2000; Kreutzner et al., 1975; Meacham & Colombo, 1980; Passolunghi et al., 1995).

Finally, all the studies reviewed above have involved assessing prospective remembering of single prospective events (e.g. Somerville et al., 1983) or multiple repetitions of the same prospective act (e.g., Guarjardo & Best, 2000; Kvavilashvili et al., 2001; Passolunghi et al., 1995). Real life prospective remembering involves the creation and realisation of multiple delayed intentions, which has been termed complex prospective memory. Only one study has investigated complex PM in children; this is the multitask study by Martin & Kliegel (2003) that we described earlier, the results of which support steady age-related increases in complex PM performance of children from 6 to 11 years of age.

3.4.2 Summary of prospective memory in children

We identified three key questions about prospective memory in children: do children have prospective memory? When and how does PM develop in childhood? Is PM in children subject to the same parameters as adult prospective memory? Although only a small number of studies have investigated PM in children, these support the presence of PM skills both in laboratory tasks and in children's everyday lives. Moreover, results broadly support the development of PM in children across the 2-14 year age range. Winograd (1988) suggested that PM is such an important skill there is good reason for it to develop in early childhood. Research to date indicates that event-based PM emerges during the pre-school years when PM is most effective in the context of everyday routines. By the end of the pre-school years children are able to use external PM cues to benefit prospective remembering in real life settings. Event-based PM continues to develop across the 6-14 year age range as children grow increasingly sophisticated in their selection and use of PM cues. The privileged status of external cues in childhood is one reason why event-based PM may emerge before time-based PM. Performance on time-based PM tasks develops across the 7-12 year age range; although all children in this age range are able to use adult-like time checking strategies, older children outperform younger children by
employing these strategies more proficiently. Children's PM is subject to similar influences to adults, which in turn indicates the presence of similar underlying cognitive processes. Like adults, children make use of cues to guide prospective remembering and these cues are most effective when they are salient. Children, like adults, find external rather than internal cues easier to work with, possibly reflecting concurrent increases in executive abilities. Children benefit from cues that specifically relate to the intended act, as do adults, for whom greater specificity results in an increased likelihood that the PM cue will be processed automatically. Children's PM appears to operate in a similar limited capacity processing system. Event-based PM may be mastered earlier than time-based PM, which is known to place greater demands on attentional capacity. Children's PM is scaffolded by everyday routines as it is easier to insert an intended action into the structure of an established routine. Similar findings have been reported in studies of older adults who perform better in naturalistic than laboratory based tasks. Children are more able to switch attention from the ongoing task to the PM task where switching does not interrupt performance on the ongoing task; in adults the same result has been taken as an indication of the involvement of executive inhibition in cue recognition and intention initiation. Children's PM is improved in real life situations where the motivation to perform the PM task is greater.

Prospective memory has been identified as the key cognitive processes supporting the organisation of future action. However other cognitive processes involved include retrospective memory and executive functions. The contribution of these cognitive processes to the organisation of future actions in children is discussed below.

3.5 Retrospective memory and the organisation of future behaviour in children

The role of retrospective memory in the organisation of future behaviour is to store the content of a to-be-performed action in memory until the action is ready to be performed (Einstein & McDaniel, 1990). For example, when you form the intention to buy bread and milk on the way home from work, prospective memory initiates your entering the shop to buy something and retrospective memory helps you to recall that it was bread you intended to buy. In adults a single dissociation between RM and PM has been observed, in that patients have been identified who have intact RM but impaired PM or who have impaired RM and impaired PM. No adult patients have been reported in whom RM is impaired.
and PM spared (Burgess & Shallice, 1997). This single dissociation supports a relationship in which retrospective memory supports prospective memory, as was modelled by Burgess et al. (2000). Very few studies have investigated the relationship between prospective and retrospective memory in children and the relative developmental trajectories of these two forms of memory remains unclear.

In their study assessing the impact of traumatic brain injury on prospective and retrospective memory, Ward et al. (2004) recorded both retrospective and prospective memory impairments in the children whose parents they interviewed. Importantly, every child who had explicit retrospective memory impairments had corresponding PM impairments and all but one child who had PM impairments also had RM impairments. This child ('Patient 10', Ward et al., 2004) was reported to have moderate PM impairments in the face of minor retrospective (explicit) memory difficulties. She was 9 years old at time of interview and had sustained a moderate TBI 15 months previously (aged 8 years) when she fell 4 metres. Her injuries were a complex fracture of the right orbit of the skull and a right fronto-parietal extradural haematoma. Further investigation would be necessary in order to establish whether this child does indeed have a selective prospective memory deficit. However, overall this pattern of results supports the single dissociation between retrospective and prospective memory observed in adults.

The relationship between retrospective and prospective memory task performance has been investigated in studies using tasks that measure both types of memory. In adult studies, PM and RM performance tend not to be related to one another (Einstein & McDaniel, 1990; Brandimonte & Passolunghi, 1994; Kidder, Park, Hertzog et al., 1997), a result that has been taken as evidence of these two forms of memory being distinct cognitive processes. Einstein and McDaniel (1990) suggest that in situations where the RM demands are greater, performance on these two forms of memory may be related. Two studies have investigated the relationship between RM and PM performance in children (Guajardo & Best, 2000; Kvavilashvili et al., 2001). Guajardo and Best (2000) assessed 3 and 5-year old children's performance on a computer picture naming task. The RM task was to recall as many of the picture names as possible at the end of each block of 10 pictures, the embedded PM task was to press the space bar each time the target picture (a duck) appeared. Results indicated that RM and PM performance correlated in 3-year old but not 5-year old children. As anticipated, RM and PM task performance was more challenging for 3-year olds than 5-year olds, it also seems that the RM
component of the PM task was more difficult as 30% of 3-year olds could not explain this aspect of the task post performance. The authors interpreted these results as evidence supporting Einstein and McDaniel’s speculation that RM and PM are associated where the RM aspect of PM task is more challenging (Guajardo & Best, 2000).

Kvavilashvili et al (2001) examined the RM-PM relationship in their study of 4, 5 and 7-year old children who played a PM game in which they named picture cards for a mole who couldn't see very well. The PM task was to hide animal pictures in a box, and the RM task was only introduced to children at the end of the game when they were asked to recall the pictures in the last stack of 10 cards. This ‘incidental recall’ approach was used to prevent older children from employing memory strategies to facilitate performance in advance (Gathercole, 1998). No relationship between RM and PM performance was observed once age was controlled for. Unfortunately correlations within age groups were not reported so it is difficult to compare these results to those of Guarjardo & Best (2000). Kvavilashvili et al (2001) do report different developmental profiles for RM and PM scores, which they interpret as evidence of different developmental trajectories for these two forms of memory.

In sum, the evidence reviewed above suggests that RM and PM in children are distinct but related processes, as they are in adults. The pattern of PM and RM impairments observed in children with TBI supports the single dissociation between RM and PM that has been proposed in the adult literature, whereby RM supports PM. Results from studies directly comparing PM and RM in children indicate that RM and PM task performance is unrelated in quite young children, except in circumstances where the RM component of the PM task is challenging in its own right. The relationship between these two processes in childhood and their relative developmental trajectories needs to be investigated further.

One final issue concerns the fact that retrospective memory itself develops rapidly during the 6-12 year period (see Schneider, 2002, for a review). Most tests of prospective memory in children are designed to control for the impact that age differences in retrospective memory could have on PM task performance. This is typically achieved by teaching children the retrospective content of the PM task (e.g., press the spacebar when you see a duck’), and checking that they can recall this information both before and after PM task performance (e.g., Guarjardo & Best, 2000; Kvavilashvili et al., 2001).
3.6 Executive functions and the organisation of future behaviour in children

Executive functions play a role in the organisation of future behaviour in adults (Bisiacchi, 2000; Burgess, 2000; Burgess et al., 2000; Kopp & Thone, 2000; Martin et al., 2003). A few studies have investigated the involvement of executive functions in the organisation of future behaviour in children; these are discussed below. Following this we summarise what is known about the development of executive functions in childhood, focusing on the executive functions most closely involved in the organisation of future behaviour.

3.6.1 Evidence for executive function involvement in the organisation of future behaviour in children

Very few studies have directly investigated the role of executive functions in the organisation of future behaviour in children; studies that have addressed this issue generally support a relationship between executive functions and performance on tests tapping future organisation skills.

Baressi (2001) reports that performance of 3-year-old children on a future-oriented task (a delayed gratification paradigm) and an executive function task testing inhibitory control (the ‘Windows Task’, Russell, Mauthner, Sharpe et al., 1991) correlated. This suggests that executive functions pay a role in the organisation of future behaviour even in very young children. Guarjardo and Best (2000) also report that executive functions influence the prospective memory performance of young children. They suggested that successful completion of a PM task relies on good planning and report that strategic planning related to performance on their event-based PM task; all participants who adopted a strategic plan (selecting and using a PM cue) performed better than those who failed to do so. 58% of 5-year olds used a strategic plan compared to only 28% of 3-year olds indicating developmental differences in strategic planning in young children.

Martin and Kliegel (2003) also report a relationship between planning and performance on their complex PM multitask test. They asked children to provide a plan of how they intended to perform the multitask; not all children were able to do so and there were age group differences with younger children finding it more difficult to make a plan. These age group differences in planning related to age
group differences in multitask performance. This result was replicated by Kliegel (2003b), who reported that 33% of 7-year olds made a plan compared to 70% of 10-year olds, and that planning was related to the success of multitask performance. Kliegel (2003b) also investigated the influence of inhibitory control on multitask performance using a within task manipulation of the computer HEXE multitask paradigm. He created a high-inhibition condition where the next stimulus item appeared on the screen automatically after successful completion of the previous stimulus item, this means that to switch subtasks children had to actively inhibit attempting this item and select a different subtask. In a low-inhibition condition participants had to click to make the next stimulus item appear within each subtask. This inhibition manipulation had a significant effect on multitask performance and 7-year old participants in particular found it more challenging than 10-year olds. This indicates that inhibitory control is important for the organisation of future actions in children and that it may be more impairing to participants who have reduced attentional capacity.

Finally, Ward et al (2004) make an observation about the relationship between executive functions and PM in their study of memory functions in children with traumatic brain injury. Two children who had severe PM difficulties also had equally severe executive dysfunction. One child is reported to have had trouble planning and organising even the most basic tasks ('Patient 1') and another needed help to organise study materials due to difficulties planning and integrating information ('Patient 2'). Further, a boy with moderate PM difficulties also had difficulties sequencing multiple prospective actions and needed to be given instructions one by one ('Patient 12'). Unfortunately, executive functions were not the focus of the study and this information is not provided for each child, although the authors comment that organising and planning difficulties overlapped more with PM deficits than RM deficits (Ward et al., 2004, page 484).

The studies reviewed above support a role for executive functions in the organisation of future behaviour. Adult models have identified some executive functions as playing a particularly important role in the organisation of future action; these are planning, cognitive flexibility, inhibitory control, performance monitoring and working memory. The normative development of each of these executive functions has been researched and this evidence is reviewed below.
3.6.2 Developmental trajectories of executive functions in childhood

In contrast to the small number of investigations of PM in childhood, a large body of research has investigated the development of executive functions in typically developing children. Studies support different developmental trajectories for different executive functions (e.g., Anderson, 1998; Anderson, Lajoie and Bell, 1995). We shall review evidence of these trajectories in school aged children.

Studies of planning skills in school age children have investigated performance on tower tasks such as the Tower of Hanoi (e.g., Klahr & Robinson, 1981; Levin, Culhane, Hartmann et al., 1991; Welsh, Pennington & Groisser, 1991) and tests of planning and organisation such as the Rey Complex Figure Test (Anderson, Anderson & Garth, 2001a). Performance on tower tasks develops rapidly between 6 to 12-years of age although even 12-year olds do not attain adult levels of performance (Welsh et al., 1991; Levin et al., 1991). Anderson and colleagues suggest that within this 6-year period the most rapid periods development occur between ages 8 to 9 and 10 to 11 years (Anderson, Anderson & Lajoie, 1996; Krikorian, Bartok & Gay, 1994). Improvements in performance on tower tasks reflect children’s developing ability to plan many moves in advance of action, to solve increasingly complex or ambiguous problems and to modify and adapt their problem solving solutions in response to feedback (Klahr & Robinson, 1981). Klahr (1994) identified the process of ‘scientific discovery’ as the most complex form of problem-solving; in this process individuals strive to attain ill defined, complex goals, working simultaneously within two problem spaces (hypothesised and evidence-based) whilst depending heavily on prior knowledge. This type of problem solving is rarely identified in young children, is present to some degree in older children and continues to develop into adulthood (e.g., Klahr, Fay & Dunbar, 1993). Planning and organisation measured by performance on the Rey Complex Figure Test (Rey, 1964) also improve consistently across the 7 to 13-year age range. In this test the child is required to copy a complex figure design and then re-draw it from memory following a 3-minute delay. Of particular interest is the relationship between how well the child organises their initial copy of the figure and their subsequent recall accuracy, indicating that planning influences retrospective memory performance and is important for day-to-day functioning. The accuracy of the initial copy and of the recalled drawing both improve consistently across the 7 to 13-year age range (Anderson et al., 2001a).
Cognitive flexibility and freedom from perseveration in children have been assessed using adult tests such as the Wisconsin Card Sort Test and the Trail Making Test. These executive functions follow a slightly different developmental course; young children typically show perseveration in their responses (Anderson, 2002), however this behaviour begins to decline in early childhood and cognitive flexibility continues to develop through middle childhood (Anderson, 1998, 2002; Chelune & Baer, 1986; Levin et al., 1991). Performance on two-dimensional set-shifting tasks such as the Wisconsin Card Sort Test is well developed by age 12-years, nearing adult levels of performance (e.g., Anderson, 1998; Chelune & Baer, 1986; Levin et al., 1991; Welsh et al., 1991). Cognitive flexibility assessed by the trail-making test shows marked improvement between ages 7 to 10-years (Anderson, 1998).

Inhibition and attention control skills evidence strong gains up to age 12-years where they reach a near adult like state of maturation (Anderson, 2002; Levin et al., 1991). Successful performance on inhibition tests emerges in infancy and early childhood (Gerstadt, Hong & Diamond, 1994) and continues to mature throughout childhood (Christ, White, Mandernach et al., 2001). By age 6-years children are able to inhibit distraction. Inhibitory skills measured on tasks such as the Go-NoGo task show developmental shifts between 7 to 8 and 9 to 12 years of age, as children become increasingly able to modulate their performance and inhibit responses (Welsh et al., 1991).

In adults, performance monitoring is incorporated into models of the prospective organisation of action in two ways. First by monitoring one's internal or external environment for PM cues and second by monitoring the success of one's own performance. Evidence from prospective memory research indicates that children are able to monitor the external environment for PM cues, as salient cues lead to more successful prospective remembering. Furthermore, this ability appears to develop across childhood as young children find it difficult to utilise cues whilst older children can do so (Guajardo & Best, 2000; Passolunghi et al., 1995). The ability to monitor one's internal environment appears to develop later in childhood and to continue to develop into the teenage years, as evidenced by studies of time-based PM (Ceci et al., 1988; Kerns, 2000). There is less information available about how children's ability to monitor the success of their own performance develops.
Studies of working memory in childhood support the same hierarchical three component model as in adults, comprising two slave systems, a phonological loop (PL) and a visuospatial sketchpad (VSSP) and a central executive (CE) component which co-ordinates and regulates the activity of these slave systems and processes the information they hold (Gathercole, Pickering, Ambridge & Wearing, 2004). Tasks placing demands on both storage and processing of information access the central executive component of working memory and are termed 'complex working memory' tasks. Evidence supports continued developmental changes in performance on complex working memory tasks between children age 6-14 years of age (Gathercole, 1998; Gathercole et al., 2004; Siegel, 1994; Swanson, 1999). These improvements in complex working memory performance are attributed to the increasing efficiency of the developing central executive component (Gathercole et al., 2004). In adults, working memory capacity constrains the processing space available to the supervisory attentional system and the process model of working memory. Developmental changes in children's prospective memory performance has been attributed to developments in processing capacity (Kerns, 2000). Working memory capacity has been shown to increase across childhood (Gathercole et al., 2004) and this increase may be attributable to increases in working memory processing capacity (e.g., Case, 1995; Halford, Wilson & Phillips, 1998) or to the speed at which information is processed in working memory (e.g., Kail, 1993; Salthouse, 1996).

3.6.3 Summary of executive functions in children

In summary, a large body of research has investigated the development of executive functions in typically developing children. This broadly supports the protracted, stage-like development of executive functions across the 3 to 12 year period (e.g., Becker Isaac & Hynd, 1987; Passler Isaac & Hynd, 1985, Levin et al., 1991; Welsh et al., 1991), with perhaps the greatest period of development occurring between 6 and 12-years of age (Anderson, 1998; Anderson et al., 1995; Tranel, et al., 1994). These studies indicate differential developmental trajectories for different executive functions and add to the growing body of evidence supporting the fractionation of executive control processes in childhood (Hughes, 2002). Considering the involvement of executive functions in the organisation of future behaviour, the concurrent development of prospective memory in childhood, particularly between ages 6- and 14-years may not simply be coincidental. Rather, it may reflect the influence of executive control functions on PM and the organisation of future behaviour.
3.7 The protracted development of the prefrontal cortex in childhood

The frontal lobes mediate the cognitive processes involved in the organisation of future behaviour. In adult research, evidence to support this assertion comes from neuropsychological studies of frontal lobe patients, from neuroimaging studies and from the recognition that executive functions, which are closely associated with the frontal cortex, play a role in the organisation of future behaviour. To the best of our knowledge no studies have directly investigated the involvement of the frontal lobes in the organisation of future behaviour in children. Child neuropsychological research has rarely focused on children with discrete frontal lobe brain injuries, although existing case reports indicate that these children do experience significant difficulties organising future behaviour. Children with developmental disorders who have executive function deficits have also been shown to have prospective memory deficits, supporting frontal lobe involvement in the organisation of future behaviour in children. The prefrontal cortex undergoes a protracted development from birth to young adulthood and this provides a strong biological basis for developmental changes in the organisation of future behaviour across childhood. Evidence for protracted structural and functional development of the prefrontal cortex is reviewed below.

3.7.1 Structural changes

Like other higher vertebrates, the human brain is moulded via a process of the initial overproduction of cells and synapses followed by selective elimination of cells via cell death and synaptic pruning (Giedd, Snell, Lange et al., 1996; Sowell, Delis, Stiles & Jernigan, 2001). The remaining cells increase their connectivity by sprouting more dendrites and increasing the number of synaptic boutons, axonal connections become faster as axons thicken and are coated in myelin sheath (Giedd et al., 1996; Giedd, Blumenthal, Jeffries et al., 1999; Klingberg, Vaidya, Gabrieli et al., 1999; Pfefferbaum, Mathalon, Sullivan et al., 1994). Following this initial overproduction of gray matter in early childhood, a corresponding reduction in gray matter and a stable increase in white matter volume are seen into adulthood, after which gray matter volume continues to decline into old age (Jernigan, Archibald, Berhow et al., 1991; Sowell, Peterson, Thompson et al., 2003), via a process of synaptogenesis (Huttenlocher & Dabholkar, 1997).
The prefrontal cortex is the region of cerebral cortex anterior to the pre-motor cortex and the supplementary motor area, it comprises between a quarter and a third of the cortex (Fuster, 1989). The prefrontal cortex is among the last cortical regions to reach full structural development (Fuster, 1989, 1998, 2000; Rubia, Overmeyer, Brammer et al., 2000; Yakolev & Lecours, 1967). Synapse elimination occurs in the frontal cortex later than in other areas (Huttenlocher, 1990; Huttenlocher & Dabholkar, 1997). It is the region of the brain with the most protracted myelination, a process that begins in the first year of life and continues well into the third decade (Giedd et al., 1996, 1999; Klingberg et al., 1999; Pfefferbaum et al., 1994; Sowell et al., 2003; Yakolev & Lecours, 1967). Brodmann’s area 10 is known to be the last area of the brain to myelinate (e.g., Giedd et al., 1996, 1999; Lewis, 1997; Paus, Zijdenbos, Worsley, Collins et al., 1999), which raises the possibility of a protracted development of the cognitive functions subsumed by this cortical area known to play an important role in the organisation of future actions in adults (e.g., Burgess et al., 2001, 2003).

In early childhood there is a robust reduction in gray matter volume of the prefrontal cortex, more so than in other areas of the brain which show shallower declines across the life span – indicating significant reorganisation at this early stage (Jernigan et al., 1991; Sowell et al., 2001, 2003). Volumes of gray and white matter continue to change between childhood and young adulthood, and these changes are likely to correspond to changes in children’s cognitive abilities during this time (Sowell et al., 2001). The increases in white matter volume identified throughout development are not constant across all brain regions (Kanemura, Aihara, Aoki et al., 2003; Paus et al., 1999). Rather, like the heterochronus development of gray matter reduction, white matter volume changes in different areas reflect the development of major fibre pathways such as the frontotemporal fibre pathway (Paus et al., 1999). Inter-hemispheric connectivity (via MRI of corpus callosum) shows non-linear growth rates (Giedd et al., 1999).

### 3.7.2 Functional changes

Until recently, it has not been possible to directly compare structural changes in the human prefrontal cortex to functional changes in typical development. This direct relation of structural change to functional change was only possible in animal studies. However, with the advent of imaging
technology such as MRI, a few studies have emerged which have attempted to directly compare structural brain changes to functional maturation.

Sowell et al. (2001) assessed children's performance on cognitive tests to seek neurobehavioural parallels for maturational changes in the brain obtained by structural MRI. They investigated the relationship between memory and planning/organisation abilities, and brain structure in thirty-five children aged 7-16-years. They found a strong relationship between frontal lobe maturation (measured by gray matter thinning) and improvements in memory functioning (measured by delayed recall of word lists). Unexpectedly, they found no relationship between frontal lobe maturation and behavioural changes in planning/organisational abilities (measured by performance on the Rey Complex Figure Test). The authors attributed the lack of a significant relationship to the task they had used to measure planning/organisation skills, claiming that it may not have adequately represented these abilities.

Functional imaging (fMRI) also provides a method of assessing functional brain changes in relation to cognitive development. When typically developing children perform tasks traditionally associated with the prefrontal cortex, there is a greater magnitude of brain activity in children than in adults (Casey, Giedd & Thomas, 2000). This finding supports the hypothesis that increases in cognitive control as children mature reflects greater synaptic loss (via pruning) as grey matter volumes decrease and white matter volume increases. There is some indication that brain activity is not only greater when children perform frontal lobe tasks, but that children also recruit different regions of the brain when performing these tasks. A recent fMRI study evaluated the development of cognitive control to frontal lobe maturation in children aged 8-12 years, and adults (Bunge, Dudukovic, Thomason et al., 2002). The basic hypothesis in this study was that cognitive control is related to frontal lobe function, and that children and adults have different levels of cognitive control underpinned by different states of maturation of the prefrontal cortex. This hypothesis was tested in an fMRI study during which children and adults performed two cognitive tasks requiring cognitive control; one task required the ability to suppress interfering stimuli, the other tested participants' ability to inhibit a prepotent response (Bunge et al., 2002). Behavioural results supported differences between the performance of children and adults on these tasks with adults out-performing children on both measures. Imaging results indicated that during both tasks children recruited different brain regions from adults. During the interference
suppression task children recruited the left ventrolateral prefrontal cortex and insula, whilst adults recruited the right ventrolateral prefrontal cortex and insula. The authors suggested this reflected a difference in the strategies adopted to suppress interfering stimuli, with children adopting a verbal strategy whilst adults adopted a non-verbal strategy. When performing the response inhibition task, adults recruited the most anterior portion of the prefrontal cortex, the dorsolateral prefrontal cortex (right side). In contrast children recruited more posterior areas of the association cortex including the bilateral precuneus, the left angular gyrus and the right mid-frontal gyrus. Overall, results support a difference in the brain regions involved in cognitive control in children and adults, reflecting the involvement of an immature brain system in children aged 8-12-years.

In contrast to this functional imaging research, studies of children with focal damage to the frontal lobes do indicate that the frontal cortex subserves executive functions even in childhood. Jacobs & Anderson (2002) assessed planning and problem solving skills in 31 children with focal frontal pathology who performed the Tower of London task. They reported that these children had particular difficulties with cognitive flexibility and goal-setting skills within this problem-solving context. Specifically, children with right prefrontal cortex lesions had self-regulatory problems and rule breaking was common amongst this group. The nature of these deficits appears to be specific to children with damage to the prefrontal cortex. Children with focal frontal lobe damage (either dorsolateral prefrontal cortex or medio-orbital frontal cortex) were compared to children with diffuse brain lesions and psychiatric patients; all three groups performed the Wisconsin Card Sort Test (WCST) and a measure of IQ (Weschler Intelligence Scale for Children, WISC). All groups had comparable IQ levels and only children with dorsolateral prefrontal cortex damage were impaired in WCST performance relative to all other groups (Filley, Young, Reardon & Wilkening, 1999).

3.7.3 Summary of maturation of the prefrontal cortex in childhood

The protracted development of the prefrontal cortex provides a biological basis for developmental change in the organisation of future behaviour across childhood. The prefrontal cortex is one of the last brain regions to reach maturation, undergoing structural changes from birth well into the third decade of life. This structural development corresponds to concurrent developments in the cognitive functions subserved by the prefrontal cortex across childhood as this region develops towards the
functional specialisation observed in adulthood. Although the involvement of the prefrontal cortex in
the organisation of future behaviour has not been directly assessed in children, the balance of evidence
supports this hypothesis and future research will be necessary to confirm it.

3.8 Summary of child research

The evidence reviewed in this chapter indicates that the ability to organise future behaviour develops
throughout childhood. Deficits in the organisation of future behaviour have been observed in children
with focal frontal lobe brain injury, with diffuse traumatic brain injury and with developmental disorders,
indicating the presence of this ability and its vulnerability to disruption. Indeed, early disruption of the
ability to organise future behaviour may be particularly debilitating. Precursors to the organisation of
future behaviour such as intention, anticipation and early planning, develop early in life and are largely
in place by the end of the pre-school years. Prospective memory is believed to be the key cognitive
process underlying the organisation of future goal-oriented behaviour. Although few studies have
investigated prospective memory in children, results point towards the emergence of prospective
memory skills in early childhood and their continued development at least until the teenage years.
Furthermore these studies support a prospective memory system in children that is subject to similar
constraints to that of adults, indicating that adult models of prospective memory are likely to apply to
children.

The role of executive functions in the organisation of future behaviour is becoming increasingly
recognised and there is strong evidence to support the protracted development of executive functions
in childhood with differential developmental trajectories for distinct executive functions. Different
executive functions are thought to be influential at different stages of prospective remembering, and it
will be interesting to examine whether the developmental trajectories of these executive functions
influence the development of the organisation of future behaviour. The protracted development of the
prefrontal cortex provides a biological basis for developmental change in the organisation of future
behaviour across childhood. Finally, multitasking has proved a promising methodology to investigate
the skills underlying the organisation of future behaviour in adults. Two studies have investigated
multitasking in typically developing children and both support developmental differences in this ability.
However, neither was designed to investigate developmental differences in the cognitive processes underlying multitasking, hence the organisation of future behaviour. We propose to design a multitasking paradigm for children that will enable us to investigate the development of the cognitive processes underlying the organisation of future behaviour in childhood.
Chapter 4: Developing a children’s multitask paradigm

Developing a children’s multitask paradigm

Multitasking has proved to be a valuable methodology for researching how adults organise their future behaviour. Multitask paradigms have enabled researchers to identify possible cognitive correlates of the organisation of future behaviour in everyday life, including planning and prospective and retrospective memory. In addition, the neuroanatomical correlates of these cognitive processes are becoming increasingly well defined and the frontal lobes have been highlighted as the key region involved in the organisation of future action. Less is known about how children develop the ability to organise future behaviour, although observations of children’s increasing autonomy indicate that they clearly do. Research into the cognitive processes underlying this skill indicates strong developmental effects, reflecting these real-life changes in children’s ability to organise their future behaviour. Developmental changes in retrospective memory and planning are well established, whilst preliminary studies of the development of prospective memory suggest that this cognitive process also develops through childhood. The ongoing maturation of the frontal lobes provides a strong neural basis for the protracted development of future organisation skills.

We wanted to develop a multitask paradigm which would enable us to investigate the development of future behaviour in children across a broad range of ages. At the time we designed our paradigm we were not aware of any other children’s multitask paradigms, as it is only recently that three children’s
multitask tests have been published (Emslie et al., 2003; Martin & Kliegel, 2003; Siklos & Kerns, 2004). Therefore, in this chapter we begin by defining what multitasking involves, we then review multitask paradigms for adults as this was our start point. We analyse each adult paradigm along several parameters to provide clues as to how best to design our children's paradigm. We then outline how we developed our children's multitask paradigm and introduce a method of administration that enables us to elicit scores for some of the cognitive processes underlying multitasking and consider how to score our multitask paradigm. Finally we compare our multitask paradigm to other paradigms that have been designed for children.

4.1 Defining multitasking

Multitasking is the term used to define the situation in which an individual is faced with the prioritisation, organisation and execution of a number of different tasks within a given period (Burgess et al., 2000). Multitasking paradigms capture the demands of problem solving in everyday life; recruiting a set of cognitive processes that combine to enable individuals to engage in purposeful, goal directed behaviour in situations that typically have few external constraints. Multitasking in everyday situations typically involves the following characteristics (Burgess, 2000):

1. A number of different tasks have to be completed within a limited period of time
2. Tasks usually differ in terms of priority, difficulty and length of time they will occupy
3. Due to either physical or cognitive constraints, only one task can be performed at any one time.
4. Performance on these tasks needs to be interleaved in order to be time effective.
5. The time to return to a task that is 'already running' is not signalled directly by the task situation. Therefore self-initiated delayed intentions must be set up and executed.
6. People decide for themselves what constitutes adequate performance and set their own targets
7. No minute-by-minute performance feedback is provided, typically failures are not signalled at the time they occur.
8. Things will not always go as planned and unforeseen interruptions (sometimes of high priority) will occasionally occur.
Laboratory multitask paradigms are designed to meet most of these characteristics. This is typically achieved by introducing a set of rules and a time limit which mirror time based and situational constraints in everyday life. For example a common rule is to limit the order in which tasks can be performed; this is representative of real life situations in which the task of ‘buying the ingredients for dinner’ is performed after ‘deciding what to prepare for dinner’ and before ‘preparing dinner.’ When reviewing existing multitask paradigms we shall focus on four key areas:

1. **Tasks**
   Multiple, distinct tasks must be performed; these ought to have different characteristics and should only be able to be performed one at a time.

2. **Time**
   In everyday life we perform multiple tasks whilst confined by time: this situation is mirrored in laboratory multitask paradigms during which multiple tasks must be attempted within a limited period of time.

3. **Rules**
   A number of rules are used to constrain multitask performance representing the constraints under which we perform actions in everyday life. Rules may be specific to one task or applied generally across all tasks. The primary function of the rules is to make it inefficient to perform the tasks sequentially, this relates to the final point, the interleaving of tasks.

4. **Interleaving/ Switching**
   Multitask paradigms are designed so that it is inefficient to perform tasks sequentially. This is because in everyday life we do not simply start and finish one task before thinking about and moving on to the next one. Everyday multitasking necessitates switching efficiently between multiple ongoing tasks at appropriate points in time. For example, preparing dinner may involve putting one item in the oven, washing another, putting something on to boil, chopping something else, turning down the temperature of the boiling pot, setting the table, checking the item in the oven etc. Switching between multiple tasks relies upon prospective memory, as to switch to another task necessitates activating a previously generated intention to perform that task. This fluid switching between tasks is the essence of multitasking and must be captured within multitasking paradigms. This is normally achieved by interleaving multiple open-ended tasks, via task order rules or characteristics of the tasks themselves.
These key characteristics of multitasking are summarised in Table 4.1. We shall review existing multitask paradigms focusing on each of these four areas.

Table 4-1: Key characteristics of laboratory multitask paradigms

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Time</th>
<th>Interleave/ Switch</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Multiple tasks</td>
<td>• Tasks must be attempted within a limited period of time</td>
<td>• Performance on these tasks needs to be interleaved in order to be time effective.</td>
</tr>
<tr>
<td>• Tasks of varying characteristics</td>
<td></td>
<td>• Participants are encouraged to switch between tasks via rules or characteristics of the tasks themselves.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>This switching requires the creation and implementation of delayed intentions.</td>
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<td></td>
<td></td>
<td>• Open ended tasks encourage the participant to switch to another task</td>
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</tbody>
</table>

4.2 Analysis of adult multitask paradigms

A number of adult multitask paradigms have been designed, in the following section we review five adult multitask paradigms according to the criteria set out in Table 4.1. These are reviewed in detail in the following pages and summarised in Table 4.2.
<table>
<thead>
<tr>
<th>Multitask paradigm</th>
<th>Tasks</th>
<th>Time</th>
<th>Rules</th>
<th>Interleaving/ Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MET</strong> Multiple Errands Test (Shallice &amp; Burgess, 1991)</td>
<td>Eight tasks. - 6 simple tasks, buy a specific object: - 1 complex time-based; be in place X at time Y - 1 complex information gathering, 4 sets of information to be written on a postcard</td>
<td>No time limit.</td>
<td>Seven rules: - Money - Time - Enter shop - Leave shop - Extra buying - Task order - Limit rule</td>
<td>Switch between simple buying tasks and more complex time-based task and information collecting task. Success is performing more than one task at once.</td>
</tr>
<tr>
<td></td>
<td>- Spatial navigation and orientation - Money handling - Shopping - Time keeping - Verbal information seeking - Writing</td>
<td>Event based (buying) Time based</td>
<td>No immediate feedback given when a rule is broken. Success is self-determined.</td>
<td>Intention to switch between tasks generated prior to performance.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Although tasks are finite they are best performed together.</td>
</tr>
<tr>
<td><strong>SET</strong> Six Elements Test (Shallice &amp; Burgess, 1991)</td>
<td>Six tasks. 2 of each type: - Dictate a route (A &amp; B) - Arithmetic (A &amp; B) - Picture naming (A &amp; B)</td>
<td>15 minutes. Covered stopwatch</td>
<td>Five rules: - Not A &amp; B together - Earlier items &gt; points - All six tasks - Correct answers get points - Errors/ omissions penalised</td>
<td>Must attempt all six tasks within the time allowed. Being unable to perform parts A &amp; B in sequence, earning more points for earlier items and being penalised for task omissions.</td>
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<td></td>
<td></td>
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<td></td>
<td>Intention to switch between tasks generated prior to performance.</td>
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<td></td>
<td></td>
<td>Open ended tasks make it necessary to interrupt performance on one task to switch to another. The dictation task could be viewed as finite.</td>
</tr>
<tr>
<td><strong>M-SET</strong> Modified Six Elements Test (Burgess et al., 1998)</td>
<td>Six tasks 2 of each type: - Dictate a route (A &amp; B) - Arithmetic (A &amp; B) - Picture naming (A &amp; B)</td>
<td>10 minutes. Covered stopwatch</td>
<td>Four rules: - Not A &amp; B together - All six tasks - Correct answers get points - Errors/ omissions penalised</td>
<td>Must attempt all six tasks within the time allowed. Being unable to perform parts A &amp; B in sequence, earning more points for earlier items and being penalised for task omissions.</td>
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<td></td>
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<td></td>
<td>Intention to switch between tasks generated prior to performance.</td>
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<td></td>
<td>Open ended tasks make it necessary to interrupt performance to switch from one task to another. The dictation task could be viewed as finite.</td>
</tr>
<tr>
<td>Multitask paradigm</td>
<td>Number of tasks</td>
<td>Task characteristics</td>
<td>Time limit</td>
<td>Number of rules</td>
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<tr>
<td>-------------------</td>
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</tr>
</tbody>
</table>
| GMT Greenwich Multitasking Paradigm (Burgess et al., 2000) | Three tasks | - Bead Sorting  
- Construction task  
- Tangled lines  
- Written (tangled lines)  
- Manual sorting (of coloured beads) | 10 minutes, Covered stopwatch | Seven rules:  
- Earlier items > points  
- Red items > points  
- All three tasks  
- Bead lid rule  
- Bead colour rule  
- One bead at a time rule  
- Tangled lines rule | No immediate feedback given when a rule is broken. Success is self-determined. | Must attempt all three tasks within the time allowed. The beads rule (cannot take out to beads of the same colour in a row) necessitates frequent switching, as does earlier items = more points rule. | Intention to switch between tasks generated prior to performance. | Interrupt performance on one task to switch to performing another. The construction task is finite, the other two tasks are open ended. |
| HEXE multitask test (Kliegel & Martin, 2000) | Six tasks | 2 of each type:  
- picture naming (A & B)  
- arithmetic (A & B)  
- real word (A & B)  
- Naming  
- Arithmetic  
- Word judgements | 10 minutes, time bar displayed on screen | Two rules:  
- Must perform some of each task  
- Task order rule, not A & B sequentially | No immediate feedback is given by the computer, participants are able to select tasks in the wrong order. Success is self-determined. | Must attempt all tasks, order rule encourages switching. | Intention to switch between tasks generated in advance of performance. | The tasks are open ended, the participant has no cues to tell them how many items are on each task; they must actively inhibit answering another item to switch to a different task. |
4.2.1 The Multiple Errands Test (MET)

The MET was developed to capture the cognitive inflexibility demonstrated by frontal lobe patients when problem solving in everyday life (Shallice & Burgess, 1991). In this 'real life' task participants (patients and controls) are set a number of errands to be completed in a small London shopping precinct. There are 8 tasks which have different characteristics: 6 straightforward 'item buying' tasks, 1 time-based task (to be at a certain location 15 minutes after starting) and 1 complex information gathering task (to collect 4 pieces of information, e.g. *name the coldest place in Britain yesterday*). The tasks make demands on shopping, writing, spatial navigation, information gathering and time-keeping skills. No time limit is placed on performance and participants are simply encouraged to complete the tasks as quickly as possible.

The MET has 7 rules, making it the most complex multitask designed. The rules are mainly 'event based' centred around buying items and are task general, e.g. *spend as little money as possible* and *you cannot enter a shop without buying something.* The time-based rule is also task general: *take as little time as possible to complete the tasks.* With prior planning, more than one task can be performed at one time, for example entering a shop to buy an item and simultaneously answering an information question. Indeed, for successful performance, where the rules are not broken, tasks must be interleaved in this way. Interleaving is also achieved by switching between tasks, buying different items and obtaining information in different shops. The environment may provide cues to indicate when to switch from one task to another (e.g. by seeing a particular kind of shop) and, in addition, switching between tasks may also be indicated by the successful completion of a task. Switching is further necessitated by the general requirement to perform all tasks. In the MET successful performance is self-determined by the participant as no immediate feedback is given where errors are made (such as entering a shop without buying something).

Compared to controls, patients with frontal lobe damage made a greater number of errors when performing the MET. They failed to accomplish as many tasks as controls, were significantly more inefficient at performing the tasks they did attempt and frequently broke the rules in quite dramatic ways, for example entering into arguments with shopkeepers caused by asking to have items for free (Shallice & Burgess, 1991).
4.2.2 The Six Elements Test (SET)

In an effort to transfer these performance traits to the laboratory, Shallice and Burgess (1991) devised the Six Elements Test (SET) to tap the same cognitive skills as the MET under more controlled and easily quantifiable conditions. Participants are presented with 6 tasks of varying characteristics and complexity; 2 dictation tasks (dictate a journey, A and B), 2 picture naming tasks (booklets of line drawings of objects, A and B) and 2 sets of arithmetic questions (in booklets A and B). In this multitask paradigm participants are required to write, dictate and problem-solve. Both the arithmetic tasks and the picture naming tasks become increasingly difficult as the participant progresses from earlier items to later items. There is a time limit of 15 minutes and participants may access a timer by lifting its cover at any time. Participants are instructed to attempt some of each task and to obtain as many points as possible during this time.

Performance is governed by a set of 5 rules. Task specific rules are: ‘in the arithmetic and picture naming tasks earlier items earn more points’ and ‘only correct items score points.’ The remaining 3 rules are task general, an ‘order rule’ (parts A and B of any task type cannot be performed one after the other), an ‘error rule’ (errors or omissions will be penalised) and an ‘all tasks rule’ (attempt all tasks before the time runs out). Tasks may only be attempted one at a time as attempting more than one at once is inefficient. Interleaving is achieved as participants must attempt every task but cannot perform the tasks as they are laid out on the table without breaking the task order rule. Tasks in the SET are open ended as there is insufficient time to complete all of each task. Therefore, switching between tasks is not afforded by characteristics of the test situation and must come from a self-initiated delayed intention to switch. Task switching is encouraged further by the rule stating that earlier items within tasks score more points than later items and that omissions of items within tasks will be penalised. Successful performance is largely self-determined, as participants decide for themselves how much of any task to attempt. No feedback is given as participants are not told if they break a rule.

Frontal lobe patients failed to perform the SET as efficiently as matched controls (Shallice & Burgess, 1991). None of the patients successfully performed all 6 tasks, they typically spent unusually short or long periods of time on the tasks they did attempt, broke the rules and carried out tasks incorrectly (e.g. dictating rather than writing the picture names).
4.2.3 The Modified Six Elements Test (M-SET)

A Modified Six Elements Test (M-SET) has been developed, in which the tasks are simpler, the rules are fewer and performance time is reduced to 10 minutes (Burgess, Alderman, Evans, Emslie & Wilson, 1998). The M-SET forms part of the BADS (Behavioural Assessment of the Dysexecutive Syndrome) test, which is a widely used test of frontal lobe dysfunction (Wilson et al., 1996). Frontal lobe patients who have difficulty organising goal directed activities in their everyday lives perform poorly on the M-SET. Their performance is characterised by increased error rates, rule breaking behaviours, and attempting a low number of tasks. Translated into everyday life, these difficulties result in patients frequently making mistakes, omitting important steps to achieve a goal and taking shortcuts which do not pay off.

4.2.4 The Greenwich Multitask Test (GMT)

Burgess and colleagues (2000) designed the Greenwich Multitask Test (GMT) to gain a clearer idea of the cognitive processes involved in multitasking. The GMT consists of 3 tasks, a bead sorting task (sorting red and green beads), a construction task (copying a 'mechano' constructed object) and a tangled lines test (tracing tangled lines from start to finish). Participants are required to attempt part of all 3 tasks within a 10 minute time limit, trying to maximise their overall score. The task demands are very simple, sorting by colour, building and tracing (along tangled lines); however overall task complexity is increased by a set of 7 rules. Three rules are task general: 'earlier items score more points,' 'red items score more points' and 'all three tasks must be attempted within the time allowed.' Four rules are task specific, three relate to the beads task: 'each time a bead is removed from the pot the lid must be replaced,' 'two beads of the same colour cannot be removed in sequence on any one turn' and 'only one bead can be removed at a time.' One relates to the tangled lines task: 'the sheet of paper must not be marked in any way except with the answers.'

In the GMT interleaving is achieved via the rules governing task performance rather than by having a greater number of tasks to perform. Participants are encouraged to switch frequently between the 3 tasks by the rules themselves. For example, the 'earlier items score more points than later items' rule encourages participants to attempt a broadly equal amount of items on each task to obtain maximum points. Similarly, the 'red items earn more points' rule encourages them to place a maximum number of
red items. Implementing these rules will influence how participants attempt the tasks. For example, in
the construction task they should construct the object using as many red parts as possible. In the
tangled lines task they should trace red lines first. The key switch task in the GMT is the beads task. On
each turn, participants can only remove beads from the pot one-by-one, but cannot remove the same
colour twice in a row. Therefore, beads can be removed red-green-red-green-red-green and so on. It is
most efficient to return to this task frequently, each time beginning the removal sequence with a red
bead. The more times the task is performed, the greater the number of red beads removed from the
container compared to the number of green beads removed.

Successful performance on the GMT is self-determined, as participants decide how to perform tasks and
organise their time. Once again no feedback is given when rules are broken, and performance on one
task must be interrupted to switch to another task. As with other multitask paradigms, patients with
frontal lobe damage performed poorly on the GMT, flagrantly abusing task rules and failing to perform
tasks efficiently (Burgess et al., 2000)

4.2.5 The HEXE Multitask Paradigm

The Heidelberger Exekutivdiagnostikum (HEXE) is a computerised version of the Six Elements Test
(Kliegel & Martin, 2000). The test has 6 tasks divided into 3 pairs (each pair has part A and part B). A
picture naming task (respond to named drawings, is the name correct or not?), a mathematics task
(respond to sums that have already been solved, are they correct or not?) and a word task (real words or
not?). The participant simply responds to stimuli by pressing a 'yes' or a 'no' button. They can switch
between tasks by selecting a different task from the bottom of the computer screen. All 6 tasks remain in
view throughout the 10 minute time limit, which is depicted by a time bar across the top of the screen
that gradually fills up. Performance is governed by 2 rules. A task order rule (you cannot attempt parts
A and B of any one task in sequence) and an all tasks rule (try some of each task before the time runs
out), both are task general. Tasks are open ended, as participants do not know how many items there
are in each. The computer restricts more than one task being attempted at any one time. Interleaving
is achieved by the two rules as all tasks should be attempted but the order in which they are to be
attempted is controlled. Targets are largely self determined and the computer does not indicate when a
rule has been broken, thus no immediate feedback is provided. In addition participants must actively
interrupt performance on one task to switch to another, as once an item has been completed the next one automatically appears. Older adults perform more poorly on this task than younger adults (Kliegel, 2003a).

4.2.6 Conclusions from adult multitask paradigms

In the above review we considered four aspects of adult multitask paradigms from which we can draw conclusions about how to proceed with designing a children’s multitask paradigm.

1. Tasks

Between 3 and 8 tasks have been used in adult multitask paradigms. The greater the number of tasks the more complex the paradigm, therefore in a children’s multitask paradigm we shall employ a small number tasks to maintain simplicity. In adult paradigms tasks can be quite challenging, such as the MET information gathering task or the SET arithmetic task. If the individual tasks are too challenging this might affect performance; for example difficult maths questions may discourage a child from attempting the second part of the maths test, thereby influencing the number of tasks attempted. Adult tests tap a variety of skills; we discounted problem solving, writing, shopping, dictation and information gathering on the grounds that these tasks may prove too complex for young children and detract from the demands of multitasking. We decided to consider building, colour-sorting and drawing as these are all activities likely to be familiar to young children. Tasks should also be open ended and only able to be performed one at a time.

2. Time

In adult tasks the time limit varies between 10 and 15 minutes. We speculated that 10 minutes would be too long for young children to perform a multitask paradigm and remain focused. In addition, we faced the following problem: if we have a small number of simple ‘open ended’ tasks these would necessarily be of overwhelming magnitude in order that they remain ‘open ended’ over such a long time period. For these reasons we decided to investigate using a shorter time limit for children to perform our multitask paradigm.

3. Rules

In adult multitask paradigms a large number of rules are used to govern task performance. Moreover these rules are a mixture of task specific rules (such as the ‘one-by-one’ beads rule of the Greenwich
test) and task general rules (such as the ‘task order’ rule in the SET). Task specific rules may be more complex to process than task general rules as they increase the specificity of information the child has to remember. Likewise fewer rules are easier to process than many rules. We decided to use a small number of simple rules to govern performance on our children’s multitask. In addition no immediate feedback should be given when rules are broken, encouraging the child to determine their own level of task success.

4. Interleaving/ Switching

All multitasks incorporate an element that encourages the interleaving of task performance, so that participants must switch between tasks rather than perform them sequentially. In the SET, M-SET and HEXE paradigms this is achieved by introducing two rules, the ‘all tasks’ rule and the ‘task order’ rule. In the Greenwich Multitask Test (GMT), task switching is encouraged by elements of the tasks themselves, for example selecting red and green beads or by constructing the ‘mechano’ model to include the greatest number of red elements. We were conscious that we would have to incorporate a switching element into our own task. As we intended to have fewer tasks than most adult multitask paradigms, we considered designing a paradigm where switching between tasks is encouraged by both the elements of the tasks themselves and the rules governing task performance. As a general principle, where the number of tasks is small and the rules governing performance are few, the necessity to switch between tasks must be greater.
4.3 Developing and piloting a children’s multitask paradigm

Following our review of adult multitask paradigms we concluded that the demands of multitasking can be simplified for children by: having fewer tasks which are child friendly, fewer rules governing performance which can mostly be applied across all tasks, a shorter time limit in which to perform the tasks and a heightened necessity to switch between tasks. These conclusions are summarised in Table 4.3. Bearing these in mind and we set out to develop a multitask paradigm for children.

Table 4-3: Multitask parameters ideal for a children’s multitask paradigm

<table>
<thead>
<tr>
<th>Multitask Parameters</th>
<th>Ideal parameters for a children’s multitask paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tasks</td>
<td>- Small number of tasks: 3 or 4</td>
</tr>
<tr>
<td></td>
<td>- Simple tasks: drawing, sorting, building</td>
</tr>
<tr>
<td></td>
<td>- 'Open-ended' tasks (cannot be completed in time allowed)</td>
</tr>
<tr>
<td>Time Limit</td>
<td>- Short time allowed &lt; 10 minutes: 3 or 5 minutes?</td>
</tr>
<tr>
<td>Rules</td>
<td>- Small number of rules: 3 or 4</td>
</tr>
<tr>
<td></td>
<td>- Task general rules (task specific rules increase memory load)</td>
</tr>
<tr>
<td></td>
<td>- No immediate feedback when rules are broken thus child determines own success</td>
</tr>
<tr>
<td>Interleaving/ Switching</td>
<td>- Tasks must be interleaved either via rules or aspects of the tasks themselves.</td>
</tr>
<tr>
<td></td>
<td>- Frequent switching between tasks should be encouraged and rewarded.</td>
</tr>
<tr>
<td></td>
<td>- Successful performance should rely upon the generation and implementation of delayed intentions</td>
</tr>
</tbody>
</table>

We developed our children’s multitask paradigm by considering each of the parameters outlined in Table 4.3. Therefore task development involved:

1. Tasks: determining the number and type of open ended tasks
2. Time: setting the time limit
3. Rules: formulating the number and type and rules
4. Interleaving/ Switch: developing the incentive to switch fluently between tasks.

We progressed through three versions before we produced our children’s multitask paradigm. Not every version was progressed through the four stages outlined above, as some ideas required further refinement. Once a version had passed through the four stages it was piloted on children.
4.3.1 Children's multitask version 1

1. Tasks

The primary goal during this phase of task development was to identify a number of suitable tasks that could be built and piloted. We decided to develop three tasks initially, and we aimed at tasks which would be suitable for young children such as sorting, drawing and building tasks.

**Sorting task.** We were attracted by the bead sorting task in the GMT, in which participants sort red and green beads into container. Red beads score more points than green beads and two beads of the same colour cannot be removed one after the other. These rules encourage the participant to switch frequently between tasks. To encourage switching in our paradigm we wanted to emulate the GMT rule of extracting one bead of each colour in turn. However, we wanted to make this implicit in the task apparatus as this reduces task complexity and memory demands. We used large wooden beads (1.5 cm diameter) to be sorted into two containers: blue beads into a blue container and yellow beads into a yellow container. We envisaged the beads being held in two separate compartments of a large perspex container, and to extract a bead the child switch a lever from one side of the container to the other. Thus children extract only one bead at a time and of each colour in turn automatically, without having to remember to do so. Children would be awarded more points for yellow beads than blue. This task would be open ended, assuming the container was large enough to hold many beads.

**Drawing Task.** We decided against asking children to draw an object or copy a picture, as older children would find this task less challenging than younger children. Also, drawing an object or picture would not constitute an 'open ended' task, as the drawing could be finished within the time allowed if it were simple, and would be too difficult if it were sufficiently complex not to be completed within the time limit. Instead, we decided to ask children to colour simple objects using wax crayons. This way the task remained simple and the number of items to colour could be unlimited. Balloons were selected as simple objects to colour and each balloon had a dot in the centre indicating which colour it should be (requiring only colour matching rather than recognising a colour word). Balloons in four colours were used: red, yellow, green and blue. In order to give some more incentive to switch between tasks, the children would colour balloons on A4 pages and when the child had coloured every balloon on a page they should place the page in a 'finished box' before starting a new one. Again, target balloons could be yellow.
Chapter 4: Developing a children’s multitask paradigm

Building task. We thought this task could be very similar to the construction task in the GMT, in which participants copied a structure made of ‘mechano’ and were awarded more points for red items that formed part of the structure. We used children’s ‘lego’ building blocks and tried to think of a structure that would be big enough so that the children could not complete it within 3-5 minutes, but simple enough to copy directly. The target yellow bricks could be embedded within the structure and bricks of the same colour would be the same size to prevent reliance on counting.

Evaluation of children’s multitask version 1
We realised a number of difficulties surrounded version 1 of the children’s multitask. First, we felt that the bead-sorting task apparatus would be too complicated to build. Also, the system we envisaged could not incorporate giving a child the chance to prioritise yellow beads, if there was no point in returning to the task to select yellow beads there would not be much incentive to switch between tasks. Yellow items could be embedded within the building task, making task switching between this and other tasks more likely, however we had serious reservations about how demanding the building task might be for younger children. We also considered whether having a task specific rule on the drawing task (‘place the page in the finished box’) would be too difficult for young children to remember. Also, whilst having the ‘finished box’ rule might encourage task switching, it would also make it difficult for children to prioritise yellow items on this task. Finally, neither the building task nor the balloons task truly constitute open ended tasks as both could theoretically be ‘finished’ within the time allowed.

4.3.2 Children’s multitask version 2

1. Tasks
We decided to try to address some of the issues raised relating to task ideas developed in version 1, and we also wanted to look for an alternative to the building task.

Sorting task. Whilst the general principal of the bead sort task remained the same as in version 1, we attempted to find a way of simplifying the apparatus. The child sorts beads into two containers, the beads are extracted from a large perspex container in which they are stored in two separate compartments. To extract a bead the child must flip the lid from one side of the container to the other.
Chapter 4: Developing a children's multitask paradigm

**Colouring task.** We decided to remove the individual rule governing colouring task performance (the 'finished box' rule), and opted instead to use one A3 size page of balloons to be coloured in. Balloons were 3cm in diameter with the appropriate colour marked in the centre of each. Target balloons were yellow and children would be free to colour only the yellow balloons in order to maximise points.

**Token task:** this was designed to replace the building task. It is a sorting task, similar in principle to the bead sorting task. We wanted to make the task look different, so we decided to use yellow and blue flat tokens (familiar to children as 'tiddly winks'), to be sorted from a large container onto a flat grid, containing rows of yellow and blue circles. The task was to fill up the rows one row at a time, some rows held a greater number of yellows than others, so children could prioritise yellow tokens.

2. **Time Limit**

We decided to implement a time limit of 5 minutes. We wanted to represent time in a way that would be fair to children of all ages, whose ability to 'tell the time' would be likely to differ. We decided to use a visual representation of time, as any form of clock or stopwatch might give children who can tell the time an advantage. We used a giant sand timer that measured five minutes to time task performance.

3. **Rules**

Three task general relate to these tasks:

- You have to do some of each task (beads, balloons and tokens) before the time runs out.
- Yellow things get the most points.
- You can only pick up one thing at a time (bead, token).

4. **Interleaving/ Switching**

The 'try some of each task' rule acts as an incentive to switch between tasks, as does the 'yellow rule' as children ought to switch between tasks to use yellow items to earn more points.
Chapter 4: Developing a children's multitask paradigm

Pilot children's multitask version 2

We felt that version 2 of the multitask was ready to be piloted with children. We wanted to assess whether the children were able to perform the tasks we had designed, to use the rules we had developed and to understand that their performance was constrained by a time limit.

Participants: 9 children were recruited from a mainstream primary school: 3 aged 6-years (2 male, 1 female) and 6 aged 8-years (4 male, 2 female).

Procedure: all children were tested individually in an empty classroom and each test session was video taped for subsequent examination. After the child’s colour recognition was assessed, the 3 tasks were laid out side by side on the table in front of the child. We varied the order in which the three tasks were placed on the table across participating children. Beginning at the child’s left we taught the child how to play each task (‘game’) and explained the rules of the game. This was done by demonstrating the tasks and rules and allowing the child to practice. Once the child was happy with this, we introduced the 5-minute sand timer and told the child that the object of the game was to score as many points as possible by playing all three games before the sand ran out. The child then played the game.

Results: are detailed in Table 4.4. On the left are the criteria by which we evaluated the children’s performance. A tick means that the child met the criterion in question, a cross means that they did not. These are discussed in the evaluation section below.

Table 4-4: Results of children’s multitask pilot version 2

<table>
<thead>
<tr>
<th>Aspect of performance assessed</th>
<th>6-year old pilots</th>
<th>8-year old pilots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 (m) 2 (f) 3 (m)</td>
<td>1 (m) 2 (f) 3 (m) 4 (m) 5 (m) 6 (f)</td>
</tr>
<tr>
<td>Learn to play all 3 tasks?</td>
<td>✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓</td>
<td></td>
</tr>
<tr>
<td>Understand the time limit?</td>
<td>✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓</td>
<td></td>
</tr>
<tr>
<td>Check timer</td>
<td>X    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓</td>
<td></td>
</tr>
<tr>
<td>Attempt all three tasks?</td>
<td>X    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓</td>
<td></td>
</tr>
<tr>
<td>Use the yellow rule</td>
<td>✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓</td>
<td></td>
</tr>
<tr>
<td>Use the ‘one-at-a-time’ rule</td>
<td>X    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓    ✓</td>
<td></td>
</tr>
<tr>
<td>Switch between tasks?</td>
<td>X    X    ✓    X    ✓    ✓    ✓    ✓    ✓    ✓</td>
<td></td>
</tr>
</tbody>
</table>

1Both children asked to stop before the timer had finished. 2This child grabbed handfuls of beads at a time, looking at the experimenter defiantly each time he did so. 3This child switched madly between tasks, placing only one item on each before proceeding to the next one, resulting in a total of 33 switches.
Evaluation children's multitask paradigm version 2

Piloting the task was very informative indeed. The results are discussed according to the evaluation criteria adopted in Table 4.4.

1. We found that children of both ages were equally able to learn and practice the three tasks and understood what was required of them to play the game.

2. All children could also relate to the concept of a 'time limit.' However, we wondered whether 5 minutes was still too long for the younger children, as two of them asked to stop playing before the time was up despite understanding that they had to 'race against' the timer.

3. Eight children checked the timer at least once during the five-minute period.

4. Eight children performed all three tasks, indicating they understood the requirement to attempt each task.

5. Five children applied the 'yellow rule' by selecting more yellow items than other colours.

6. Eight children understood and adhered to the 'one-at-a-time' rule. Only one child broke the 'one-at-a-time' rule by grabbing handfuls of beads, he appeared to know he was breaking the rule because he looked up defiantly each time he did so, but of course received no feedback.

7. Not all the children switched fluently between tasks. One 6-year old attempted only two of the tasks before he ran out of time. Five other children did perform all three tasks, but moved sequentially from one to the next, e.g., from beads to balloons to tokens, never returning to a task previously attempted. These children tended to perform the tasks in the order they were arranged across the table, moving left to right. One further child switched between tasks wildly, placing only one item on each before moving on to the next, accumulating 33 switches. This was an inefficient strategy as such frequent switching resulted in him placing fewer items overall than peers who stayed on each task for longer. Two children (one 6-year old and one 8-year old) performed some of all three tasks, then returned to others tasks. Only these children could be said to be switching fluently between tasks.

Conclusions: we concluded that children could perform 3 tasks, understand the time limit and apply the rules. However, we needed to revise how we encouraged task switching and to reduce the time limit in future versions of the multitask paradigm.
4.3.3 Children's multitask paradigm version 3

Task switching proved to be the most difficult aspect of multitasking to implement in our paradigm. How could we influence the paradigm to compel children to switch between tasks to achieve the most efficient performance? We finally solved this problem by changing the task apparatus by clustering items and developing a 4th rule. Below, we outline the process by which we arrived at this solution, following which we detail version 3 of the paradigm and the results of the pilot study.

'Clustering items'

In version 1 of the paradigm we included bunches of balloons rather than individual balloons in the belief that this would encourage children to switch between tasks. This follows from prospective memory research which indicates that children find it easier to switch attention from an ongoing task to a prospective memory task if they are at a natural break in the ongoing task (Kvavilashvili et al., 2001). We decided to try to facilitate children's switching by creating natural breaks in our tasks by 'clustering' items together. For example, if we had multiple containers into which to sort beads, multiple bunches of balloons on a large sheet of paper and multiple grids onto which to sort tokens.

*Within task switching - moving between clusters*

Clusters would contain only yellow or blue items. In this way children would be tempted to choose between clusters within each task, for example by choosing yellow clusters over blue. We realised that we could vary the size of these clusters to make some more or less attractive to perform than others.

*Between task switching – the 4th rule*

How could we transfer this process of 'weighing up' which items to perform from occurring within tasks to occurring between tasks? The answer came by adding a 4th rule: bonus points would be awarded for every full cluster within a task. In this way the most attractive items in each task were the smallest clusters of target items, as they were fastest to fill and scored more points. We hoped that by introducing this rule and the concept of clusters, children would be encouraged to move between tasks, attempting to complete a large number of small clusters of target items to score more points. Optimum performance would thus involve children comparing clusters of items between tasks, to decide which clusters were smaller or easier to fill up across all three tasks.
1. Tasks

**Sorting task:** in this bead sorting game, children are presented with a large box containing 150 blue and 150 yellow wooden beads (1.5 cm diameter). Behind the box of beads is a tray containing 8 upright transparent perspex containers, of varying shapes and sizes. 4 of the containers are marked with a blue label and 4 with a yellow label. There are 2 tall tubes (1 blue, 1 yellow) holding 14 beads each, 2 shorter rectangular containers (1 blue, 1 yellow) holding up to 25 beads each, 2 similar square containers (1 blue, 1 yellow) holding up to 25 beads each and two large circular containers (1 blue, 1 yellow) holding up to 70 beads each. These containers are embedded in a tray in positions that are kept constant for every child. The object of the bead sorting game is to sort the beads one-by-one into the appropriate coloured containers.

**Colouring task:** in this colouring game, we quickly discovered that an A3 sheet of paper does not hold very many bunches of 3 cm diameter balloons. We decided to replace the balloons and cluster stimuli together in a different way, we selected ‘caterpillars.’ These are constructed by joining circles (2 cm in diameter) in a row to form a ‘body’ and drawing a face on one end. Each ‘body’ circle has a coloured dot in the centre indicating what colour the caterpillar should be. The caterpillars are arranged on an A3 sheet of paper, 6 blue and 6 yellow. They vary in length according to the number of circles they are composed of: 2 caterpillars are 14 circles long (1 yellow, 1 blue), 4 are of medium length (7-10 circles, 2 yellow, 2 blue) and 4 are short (3-4 circles, 2 yellow, 2 blue). The object of the caterpillar game is to colour the ‘body’ circles of the caterpillars one-by-one in the appropriate colour.

**Token task:** in this sorting game, children are presented with a tub containing 300 flat blue and yellow tokens (1cm diameter, 150 of each colour). The tub of tokens is placed beside a large red plastic board upon which are drawn 10 grids of varying size (5 blue and 5 yellow). The grids are constructed from rows of adhesive circles of equal size to the counters. Two grids are large (1 yellow, 1 blue) with spaces for 14-16 tokens, two grids are medium (1 yellow, 1 blue) with spaces for 8-9 tokens, and four grids are small (2 yellow, 2 blue) with spaces for 3-4 tokens. The object of the token game is to place the appropriate tokens one-by-one onto the rows of circles inside the grids.

2. Time limit

We used a giant 3-minute sand timer to time performance on this version of the multitask, having found that 5 minutes was too long for some children.
3. Rules

Three rules are task general, the one-by-one rule is specific to the bead and token tasks:

- You have to do some of each task (beads, caterpillars and tokens) before the sand runs out.
- Yellow things get the more points than blue.
- You can only pick things up one-by-one (one bead, one token).
- Full items (pot, caterpillar or grid) score extra bonus points.

4. Interleaving/ Switching

As discussed above, the incentive to switch comes from the combination of rules and elements of the tasks themselves (the different sizes of clusters). Switching is made attractive by the requirement to attempt all three tasks, by scoring extra bonus points for filling clusters of items (participants should look for smaller, easily filled clusters within and between tasks) and by scoring extra points for yellow items (participants should look for small clusters of yellow items within and between tasks).

Pilot children’s multitask version 3

We piloted version 3 with ten children aged 6 and 8-years-old, the main aim was to see whether our ‘task switching’ concept would work.

Participants: ten children from two mainstream primary schools participated. Seven aged 6-years (4 male, 3 female) and three aged 8-years (all female).

Procedure: all children were tested individually, in an empty classroom and each test session was video taped for subsequent evaluation. After the child’s colour recognition had been assessed, the 3 tasks were placed side by side on the table in front of the child. The order in which the three tasks were laid out on the table was alternated between participating children. Beginning at the child’s left we taught the child how to play each ‘game’ by demonstrating the tasks, introducing the rules and time limit and clearly explaining the best ways to score points. The child was then allowed to practice the tasks. Once the child was happy with the tasks and understood the rules, they performed the multitask paradigm under timed conditions.

Results: are detailed in Table 4.5. On the left are the criteria by which we evaluated the children’s performance. A tick means that the child met the criterion in question, a cross means that they did not. These results are discussed in the evaluation section below.
Table 4-5: Results of children's multitask pilot version 3

<table>
<thead>
<tr>
<th>Aspect of performance assessed</th>
<th>6-year-olds</th>
<th>8-year-olds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5 6</td>
<td>1 2 3 (f)</td>
</tr>
<tr>
<td>Learn to play all 3 tasks</td>
<td>✓ ✓ ✓ ✓ ✓ ✓</td>
<td>✓ ✓ ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Understand time limit</td>
<td>X ✓ ✓ ✓ ✓ ✓</td>
<td>✓ ✓ ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Check timer</td>
<td>✓ ✓ ✓ ✓ ✓ ✓</td>
<td>✓ ✓ ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Attempt all three tasks</td>
<td>✓ ✓ X 1 ✓ ✓</td>
<td>✓ ✓ X 1 ✓ ✓</td>
</tr>
<tr>
<td>Use yellow rule</td>
<td>X X ✓ ✓ ✓ ✓</td>
<td>X ✓ ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Use 'one-at-a-time' rule</td>
<td>✓ ✓ ✓ ✓ ✓ ✓</td>
<td>✓ ✓ ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Use 'fill' rule</td>
<td>✓ ✓ ✓ ✓ ✓ ✓</td>
<td>✓ ✓ ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Switch between tasks</td>
<td>✓ ✓ X X ✓ ✓</td>
<td>✓ ✓ X ✓ ✓</td>
</tr>
</tbody>
</table>

1 Two children performed two out of three tasks and ran out of time to move onto the third. 2 Two children only attempted one of the three tasks. 3 Two children failed to move on from the third task and stayed doing this until time ran out, thus not fluently switching between tasks.

Evaluation of children's multitask paradigm version 3

1. Children of both ages were equally able to learn and practice the three tasks.
2. Most of the children could relate to the concept of the time limit. Only one child appeared to misunderstand stating that he had '1 minute' in which to play the game. Although he didn't check the timer once, he managed to perform all three tasks and to switch fluently between them. In contrast to the 5 minute time limit, no child stopped before the time was up.
3. Nine of the ten children checked the timer during task performance.
4. Two thirds of the children in each age group performed all three tasks, of those who didn't; two ran out of time during the second task and two only attempted to perform one task.
5. Five of the ten participants used the yellow rule and selected more yellow items than blue.
6. Seven of the ten participants used the one-at-a-time rule, whilst three cheated and broke this rule.
7. All the children succeeded in filling up complete clusters of items and we were confident that they were able to relate to the concept of 'filling things up.'
8. Of the six children who attempted all three tasks, four switched fluently between them. This is in contrast to the two of eight children who managed to switch fluently between tasks in our version 2 pilot study.
Conclusions and final changes to children’s multitask paradigm version 3

We felt strongly that our new rules had increased the incentive to switch, and that the children who failed to perform all three tasks or to switch efficiently may be reflecting individual or developmental differences in multitasking ability. As such we decided to keep the switch incentives we had devised.

We revised some minor aspects of the tasks based upon the children’s performance during the pilot test. For example, we noted that children called the tokens ‘counters’ and decided to rename this game. We also observed that exaggerating the concept of bonus points for full items helped children to understand this rule better, so we decided to tell children that full clusters get ‘lots of extra bonus points.’ Finally the children’s own performance prompted us to change the ‘one-at-a-time’ rule to become task general. This is because some children performed the caterpillar task by scribbling over an entire caterpillar, rather than colouring the circles in ‘one-by-one’ as they had been instructed to. With these changes in place, we had developed the tasks and the rules for our children’s multitask paradigm.

In the next section we detail the final version of our multitask paradigm including materials, the administration procedure we selected and scoring system we developed. We decided to call our multitask test the *Battersea Multitask Paradigm* in recognition of the area of London in which we piloted it.
4.4 The Battersea Multitask Paradigm

Our children’s multitask paradigm has 3 simple tasks governed by 4 simple rules, to be performed in 3 minutes. Below we outline the tasks and the rules of our paradigm. Following the task description we discuss how we developed a procedure for administering the Battersea Multitask Paradigm and introduce a scoring system related to this administration procedure. This is the final version of our children’s multitask paradigm, which we will refer to in subsequent chapters.

4.4.1 Battersea Multitask Paradigm

1. Tasks

The 3 tasks comprising the Battersea multitask paradigm are a bead sorting game, a counter sorting game and a caterpillar colouring game. In each game the child must place or colour small items (beads, counters, caterpillar circles) in order to fill a larger ‘cluster item’ (a pot full of beads, a square full of counters or a caterpillar fully coloured in). In each task items are yellow or blue. The test materials for all 3 tasks are detailed in Figure 4.1.

**Beads Task:** This is a bead sorting game. Children are presented with a large box containing 300 blue and yellow wooden beads (1.5 cm diameter, 150 of each colour). Behind the box of beads is a tray containing 8 upright transparent perspex containers, of varying shapes and sizes. 4 of the containers are marked with a blue label, and 4 with a yellow label. There are 2 tall tube containers (1 blue, 1 yellow) holding 14 beads each, 2 shorter rectangular containers (1 blue, 1 yellow) holding approx. 25 beads each, 2 similar square containers (1 blue, 1 yellow) holding approx. 25 beads each and 2 large circular containers (1 blue, 1 yellow) holding approx. 70 beads each. These are embedded into the grey tray in positions that are kept constant for every child. The object of the bead sorting game is to sort the beads one-by-one into the appropriate coloured containers.

**Caterpillars Task:** This is a colouring game. Children are presented with an A3 sheet of paper with 12 caterpillars of varying length, half blue and half yellow, and two crayons (1 yellow, 1 blue). The caterpillars are constructed from circles (approx. 2 cm diameter), solidly coloured circles with eyes, mouth
and antennae represent the head, and each 'body' circle has a coloured dot in the centre. 2 caterpillars are 14 circles long (1 yellow, 1 blue), 4 are of medium length (7-10 circles, 2 yellow, 2 blue) and 4 are short (3-4 circles, 2 yellow, 2 blue). The object of the caterpillar game is to colour in the 'body' circles of the caterpillars one-by-one with the appropriately coloured crayon.

**Counters Task.** This is a sorting game. Children are presented with a tub containing 300 flat blue and yellow counters (1cm diameter, 150 of each colour). The tub of counters is placed beside a large red plastic board upon which are drawn 10 squares of varying size (5 blue and 5 yellow). The squares are constructed from rows of adhesive circles of equal size to the counters. 2 squares are large (1 yellow, 1 blue) with spaces for 14-16 counters, 2 squares are medium (1 yellow, 1 blue) with spaces for 8-9 counters, and 4 squares are small (2 yellow, 2 blue) with spaces for 3-4 counters. The object of the counters game is to place the appropriate counters one-by-one onto the rows of circles inside the squares.

*Figure 4-1: The Battersea Multitask Paradigm*
2. **Time limit**

The total time allowed to perform the tasks is 3 minutes displayed visually to the children by a giant sand timer.

3. **Rules**

Performance is also constrained by 4 task general rules:

- Try all three games before the sand runs out.
- Yellow things get more points than blue.
- You get lots of extra bonus points for every pot, caterpillar or square you fill up.
- You can only do things 'one-by-one' *i.e.* one bead, one counter in your hand/ one circle to be coloured at a time.

4. **Interleaving/ Switching**

In our paradigm the necessity to switch between tasks is embedded in the tasks themselves (clusters of items) and the rules governing their performance which encourage participants to switch between tasks to earn more points.

5. **How to 'play the game'**

We summarise the best way to play the game to score points and avoid rule breaking:

- The object of the game is to score as many points as possible without breaking any of the rules.
- The way to avoid rule breaking is to attempt all 3 tasks and not to take more than one item at a time.
- The way to maximise points is to focus on yellow items (as they are worth more than blue), and to focus on small items that are easy to fill (as 'full' items earn extra bonus points).
- In each of the 3 tasks the child is presented with a variety of large and small, yellow and blue items. Comparisons to identify the 'best' items to fill can be made within and between tasks, thereby making it necessary for the child to switch between tasks in order to maximise performance.
Chapter 4: Developing a children's multitask paradigm

4.4.2 Battersea Multitask Paradigm administration procedure

Having decided on the tasks to use in the multitasking paradigm and the rules we will use to govern performance on these tasks, we wanted to develop an administration procedure for our paradigm.

We were attracted to administration procedure used by Burgess and colleagues (2000) to administer their Greenwich Multitask Test (GMT). The GMT was designed to gain a clearer idea of the various cognitive processes involved in multitasking. This was in response to the recognition that a multitask situation places various cognitive demands on an individual, some of which are specific to multitasking, such as the realisation of delayed intentions, and some of which are non-specific, such as retrospective mnemonic demands. Burgess and colleagues measured these different cognitive processes by administering the GMT as part of an invariant behavioural sequence. At each stage of this sequence a behavioural variable is generated:

1. Participants **learn** the 7 rules of the GMT
2. They **plan** how to perform the test.
3. How well they **follow** their plan is assessed.
4. How successfully a participants’ **perform**s the test is assessed.
5. Participants are asked to **recount** what they achieved during performance.
6. Finally participants are asked to **remember** the rules of the test.

Each of these behavioural variables contribute to the cognitive processes underlying multitask performance, as was modelled by Burgess and colleagues (2000) using structural equation modelling.

- Rule learning and memory relate to a **retrospective memory** factor, as they measure knowledge about the content of the to-be-performed intentions.
- Plan relates to a **planning** factor, representing the participant’s ability to generate a plan of how they will perform multiple tasks.
- Follow, perform and recount relate to a **prospective/ intention** factor, representing cognitive processes involved in the organisation of prospective actions.

*This administration procedure lends itself to evaluating the cognitive processes underlying multitasking, hence the cognitive processes underlying the organisation of future behaviour.*

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We hoped that using this administration procedure with children would enable us to investigate the
cognitive processes underlying the organisation of future behaviour in childhood. The administration
procedure we adopted for our developmental sample and the corresponding behavioural measures are
summarised in Figure 4.2. The exact instructions and administration procedure are detailed in Appendix
1 and summarised below.

*Figure 4-2: Invariant administration sequence of the Battersea Multitask Paradigm*

<table>
<thead>
<tr>
<th>Behaviour (stage of task administration)</th>
<th>Variable generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free and cued recall of the 4 rules of the paradigm</td>
<td>Learn</td>
</tr>
<tr>
<td>Ask children how they intend to ‘play the game’</td>
<td>Plan</td>
</tr>
<tr>
<td>What children did in comparison to what they planned to do?</td>
<td>Plan Follow</td>
</tr>
<tr>
<td>How children score overall when performing the task</td>
<td>Perform</td>
</tr>
<tr>
<td>Children’s ability to describe what they have done</td>
<td>Recount</td>
</tr>
<tr>
<td>Retrospective free and cued recall of 4 rules</td>
<td>Remember</td>
</tr>
</tbody>
</table>

First the child is taught how to play each of the 3 tasks separately and allowed to practice. This is
achieved using precise instructions and this stage ends once the child is happy with the tasks.

- **Learn**: assesses the child’s ability to learn the rules governing task performance, children are taught
  the 4 rules and their knowledge of them is assessed by both free and cued recall.
- **Plan**: the plan variable measures the child’s ability to formulate a plan of how they will perform the
  paradigm. The child is asked to generate a verbal plan of how they intend to play the game in
response to the question – ‘how will you play this game to get as many points as you can?’ The child’s plan is recorded verbatim for later scoring.

- **Plan Follow:** measures the child’s ability to follow through prospective intentions. What the child does during multitask performance is compared to what they intended to do in their original plan.

- **Perform:** assesses how well the child performs multiple tasks and measures the ability to organise multiple future activities. What the child does whilst playing the game is recorded and assessed.

- **Recount:** assesses the child’s ability to gauge what they achieved during performance and as such measures the ability to monitor and update performance goals. The child is asked to recount details of their performance in response to the question - ‘show me what you did when you played the game and tell me why?’ Responses are recorded verbatim for scoring.

- **Remember:** memory for the rules of the paradigm is assessed post performance as the child is asked to recall the rules of the game freely and by answering cued questions.

### 4.4.3 Battersea Multitask Paradigm scoring system

Participants’ performance at each stage of the administration procedure is recorded and scored. We wanted to design a scoring system that would measure the various cognitive processes underlying multitasking and capture the complexity of performing multiple tasks. In most multitask paradigms designed for adults the focus has been on scoring the number of tasks attempted and the number of rules broken. We wanted to investigate whether children can learn and remember a set of rules, if they are able to generate a plan of how to co-ordinate performing multiple tasks, if they adopt strategies to help them perform all the tasks, if they can implement the rules of the paradigm to maximise their performance and if they can monitor and update their performance goals online. This was a challenging system to develop but we feel it successfully reflects the diversity of cognitive skills involved in multitasking. Our scoring system is described in some detail below and further information can be found in the scoring manual (Appendix 2). Scores for individual items at each stage of administration are summed to yield ‘composite scores’ which represent the 6 key variables generated by the multitask paradigm.
Rule Learning and Memory

Learning and memory for the rules are scored in the same way by measuring both free and cued recall of the rules before (learn) and after (remember) the child performs the multitask game. **Free recall** of the rules is scored by assessing the number of rules the child is able to recall without prompting and answers are graded. 2 points are awarded for answers in which the child shows understanding of the generality of rules across all tasks and the specific relations within the rule, for example stating that 'yellow is more points than blue' where the more than relationship is specified. 1 point is awarded when the child fails to apply the rule to all three tasks, or where they fail to mention relationships within the rule, for example 'yellow is most points' fails to specify the more than blue relationship. 0 points are awarded when the child omits a rule. Therefore free recall rule learning scores range from 0-8, as is detailed in Table 4.6.

*Table 4-6: Scoring free recall of the rules*

<table>
<thead>
<tr>
<th>Rule</th>
<th>Two point answer</th>
<th>One point answer</th>
<th>Zero point answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>All 3 games</td>
<td>Try all three games</td>
<td>N/A</td>
<td>No answer given</td>
</tr>
<tr>
<td>Yellow more points than blue</td>
<td>Yellow &gt; blue (specific mention of yellow in relation to blue)</td>
<td>Yellow more points (no recognition of yellow superiority over blue) Yellow beads more points (no recognition of general rule)</td>
<td>No answer given</td>
</tr>
<tr>
<td>Lots of extra bonus points for everything you fill up</td>
<td>Bonus points for filling up Extra points for filling up Lots of points for filling up * understand concept of additional points and generality of rule</td>
<td>Points for filling up * no recognition of additional points Fill up squares get a bonus * no recognition of generality of rule</td>
<td>No answer given</td>
</tr>
<tr>
<td>Do things one-by-one</td>
<td>Pick things up one-by-one Take beads, counters one-by-one and do circles one-by-one * recognition of generality of rule</td>
<td>Pick up beads one-by-one * no recognition of generality of rule</td>
<td>No answer given</td>
</tr>
<tr>
<td><strong>Total Score</strong></td>
<td><strong>Ranges from 0 to 8 points</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Cued recall** of the rules assesses the child's knowledge of the rules and parameters of the game via a series of 9 questions. The question relating to the yellow rule is scored as a 1 point or 2 point answer according using the criteria outlined above. The remaining 8 questions are scored as correct (1 point) or incorrect (0 points). 4 questions are direct questions about the rules, e.g., 'how many of the games should you try?' and 5 assess the child's knowledge of other parameters of the paradigm. Scoring of
Chapter 4: Developing a children's multitask paradigm

cued questions is detailed in Table 4.7. Free and cued recall scores are summed to give the composite 'rule learning' score for children's knowledge of the rules assessed before they play the game, and to give the 'rule memory' score for children's knowledge of the rules after they have played the game. Each score has a maximum of 18 points (range 0-18).

Table 4-7: Scoring cued recall of the rules

<table>
<thead>
<tr>
<th>Cued knowledge question</th>
<th>Correct answer (points awarded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>How many games are there? (3)</td>
<td>3 (1 point)</td>
</tr>
<tr>
<td>What is special about yellow things?</td>
<td>More points (1 point)</td>
</tr>
<tr>
<td></td>
<td>More points than blue (2 points)</td>
</tr>
<tr>
<td>How many of the games should you try?</td>
<td>All/ 3 (1 point)</td>
</tr>
<tr>
<td>How long do you have to play the games?</td>
<td>3 minutes/ until the sand/ time runs out (1 point)</td>
</tr>
<tr>
<td>Do you think you could finish all of the games before the sand runs out?</td>
<td>No (1 point)</td>
</tr>
<tr>
<td>When does the game stop?</td>
<td>After 3 mins./ when the sand/ time runs out (1 point)</td>
</tr>
<tr>
<td>Can you have more than one thing in your hand?</td>
<td>No (1 point)</td>
</tr>
<tr>
<td>Why should you go as quickly as you can?</td>
<td>Get lots of points/ before time runs out/ fill things up (1 point)</td>
</tr>
<tr>
<td>Why should you try to fill up squares and caterpillars and pots?</td>
<td>To get lots of extra/ bonus points (1 point)</td>
</tr>
<tr>
<td>Total Score</td>
<td>Ranges from 0 to 10 points</td>
</tr>
</tbody>
</table>

[2] Planning

Prior to playing the game, each child generates a verbal plan of how they intend to perform the paradigm to score as many points as possible. A plan to score maximum points would incorporate 3 main elements; the intention to perform all 3 tasks, the intention to prioritise yellow items and the intention to fill items to earn bonus points. The child's plan is scored to assess the presence of each of these elements. At the most basic level a plan ought to include the intention to perform all 3 tasks and we decided that if children did not spontaneously plan to do this, we would prompt them to do so rather than leave them with the impression that they did not have to perform all 3 tasks. This is reflected in the scoring system for 'plan task', 2 points are awarded for each task that the child plans to perform without prompting, and 1 point for each task planned with prompting (range 3-6 points). Children were awarded a point for each task on which they planned to prioritise yellow items, 'plan yellow' (max 3 points) and for
each task on which they planned to fill items, 'plan fill' (max 3 points). A general statement such as “I'll do more yellows on them all” would be awarded 6 points for including all tasks and 3 points for planning to prioritise yellow items on all tasks. If the child’s plan specifies the order in which they intend to perform the tasks this is noted but not scored as general statements do not include this information. The plan score is detailed in Table 4.8, the maximum plan score possible is 12 points (range 3-12).

Table 4-8: Plan scoring system

<table>
<thead>
<tr>
<th>Planning Variable</th>
<th>Correct answer (points awarded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of tasks planned (plan-task) &amp;</td>
<td>I’ll play them as well as I can (implicit)/ I’ll do them all (explicit) = 6 points</td>
</tr>
<tr>
<td>order in which they are planned</td>
<td>I’ll do the beads (specific task mentioned) = 2 points per task (unprompted)</td>
</tr>
<tr>
<td></td>
<td>I’ll do the beads (specific task mentioned) = 1 point per task (prompted)</td>
</tr>
<tr>
<td>Plan to use yellow rule (plan-yellow)</td>
<td>I’ll do lots of yellow to get more points (general) = 3 points</td>
</tr>
<tr>
<td></td>
<td>I’ll use more yellow counters (specific task mentioned) = 1 point per task</td>
</tr>
<tr>
<td>Plan to use fill rule (plan-fill)</td>
<td>I’ll fill things up to get more points (general) = 3 points</td>
</tr>
<tr>
<td></td>
<td>I’ll fill up squares (specific task mentioned) = 1 point per task</td>
</tr>
<tr>
<td>Total Score</td>
<td>Ranges from 3 to 12 points</td>
</tr>
</tbody>
</table>

[3] Plan Follow

After the child has performed the multitask paradigm, we assess how well they followed their plan; the plan follow score is closely linked to the quality of the original plan as it measures the child’s ability to follow through previously generated intentions. Each child planned to perform all 3 tasks and they were penalised if they failed to do this (number of tasks planned minus number of tasks performed). If the child planned to perform the tasks in a specific order and deviated from this plan they were also penalised (order planned minus discrepancies in order performed). If the child planned to prioritise yellow items and failed to do so points were subtracted (if yellow beads planned but not prioritised, subtract 1 point etc.). Points were subtracted if the child planned to fill clusters on a task but did not then fill a cluster of items before moving on to the next (if planned to fill whole caterpillar but did not do so before beginning another caterpillar or another task, minus 1 point etc.). The scoring system for plan follow is outlined in Table 4.9, scores range from 0 to 12; however it is important to remember that each child’s score is constrained by the quality of their original plan.
Table 4-9: Plan follow scoring system

<table>
<thead>
<tr>
<th>Plan-following Variable</th>
<th>Points subtracted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Follow plan-task score</td>
<td>Number of tasks planned (score 3-6) Subtract one point for each task not performed Subtract one point for each discrepancy or omission from the order in which tasks were planned (if tasks were not planned in any particular order, no points are subtracted)</td>
</tr>
<tr>
<td>Follow plan-yellow score</td>
<td>Tasks on which child planned to prioritise yellow (score 0-3) Subtract one point for tasks on which yellow was planned but not prioritised</td>
</tr>
<tr>
<td>Follow plan-fill score</td>
<td>Tasks on which child planned to fill clusters (score 0-3) Subtract one point for each task on which the 1st cluster attempted was not filled prior to switching</td>
</tr>
<tr>
<td>Total Score</td>
<td>Ranges from 0 to 12 points</td>
</tr>
</tbody>
</table>


The child’s performance on the multitasking paradigm is the most complex score as it measures the ability to co-ordinate performance on multiple tasks and represents the combined activity of various cognitive processes underlying multitasking. Three aspects of performance are considered: strategic performance (where the child uses the rules governing task performance to strategic advantage to gain points), penalty performance (where the child breaks rules or makes errors for which they are penalised and lose points) and task switch performance (representing the efficiency with which children switch between the tasks).

(a) Task switching performance is either scored as ‘efficient’ (credited 2 points) or ‘inefficient’ (penalised 2 points). Our multitask paradigm was designed to encourage children to strategically switch between tasks to earn points, in order to score switch performance we had to define where children did not switch often enough to be efficient, and where they switched so often their performance could no longer be described as efficient. We developed our task switching scoring system based on data from our two pilot studies. In order to switch efficiently children must at least perform all 3 tasks (2 switches), however we observed that some children switched from the 1st to the 2nd to the 3rd task and then stayed on the 3rd task until the time ran out, even if they had finished filling all the small yellow items on that 3rd task. Children who switched in this way were not truly interleaving task performance and we decided to penalise children who switched only twice. Efficient switching must encompass one further switch to a different task; therefore the lower limit of the ‘efficient range’ is 3 switches. The upper limit for efficient
switching will in part be determined by the performance of the group being assessed. For example children in our pilot sample who switched more than twice switched between 3 and 33 times. The child who switched 33 times was extremely inefficient as he placed only 1 item on each task, failing to take into account the ‘fill’ rule. The remaining children switched between 3-10 times and paid attention to filling clusters and to selecting yellow items. We chose not to set a rigid upper limit of 10 switches for efficient performance as we speculated that older more dextrous children may switch 11, 12 or even 13 times whilst remaining efficient. We therefore decided to set the upper limit of the efficient switching range according to the children participating in each study, penalising outlier scores.

(b) Strategic performance points are awarded according to how the child uses the rules of the paradigm to strategically gain points. For the ‘all 3 tasks’ rule points are awarded for the number of tasks the child attempts (1 point for each task). For the ‘yellow is more than blue’ rule points are awarded for each task on which the first item placed is yellow (1 point for each task) and for each task on which yellow items are prioritised overall (comparison of total number of yellow items to blue is done using a binomial formula, see Appendix 2). If on any task a child manages to fill all the smallest yellow clusters and proceeds to fill the smallest blue clusters, a sensible strategy, points are still awarded for prioritising yellow as all the small yellow clusters are full. For the ‘fill earns bonus points’ rule points are awarded for each task on which the first item is placed in a small cluster, as this is quickest to fill (2 points for smallest clusters, 1 point for medium clusters, 0 points for largest clusters) and each task on which the child fills a whole cluster before moving on to another cluster or task (1 point for each task). All these scores are combined to form a ‘strategic performance score’ with a minimum of 1 (at least one task must have been attempted) and a maximum of 18 points.

(c) Penalty performance points are deducted when the child breaks the ‘one-by-one’ rule or makes a performance error. Children are penalised (minus 1 point) for each task on which they break the ‘one-by-one’ rule. In addition, the number of times children break the rules is recorded but not added to the penalty score. During piloting we observed that children sometimes made placement errors, e.g., placing a yellow item in a blue container. Research with frontal lobe patients has highlighted the errors they make as a distinguishing facet of their performance (e.g., Shallice & Burgess, 1991) and we wanted to be able to measure any developmental changes in error rates in our paradigm. Children are penalised...
(minus 1 point) for each task they make an error on, the number of uncorrected errors made is also recorded but does not contribute to the penalty score. These scores are combined to form a ‘penalty performance score’ with a minimum of -6 and a maximum of 0 points.

Switch score, strategic performance score and penalty performance score are summed to give a composite ‘multitask performance score’, with a maximum of 20 points. This performance scoring system is detailed in Table 4.10.

**Table 4-10: Multitask performance scoring system**

<table>
<thead>
<tr>
<th>Performance Variable</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task attempt score</td>
<td>1 point for each task attempted</td>
</tr>
<tr>
<td>Yellow item first</td>
<td>1 point for single yellow item played first on each task</td>
</tr>
<tr>
<td>Small cluster first</td>
<td>2 points for small, 1 point for medium, 0 points for large</td>
</tr>
<tr>
<td>Fill item first</td>
<td>1 point if the first item attempted is full before proceeding</td>
</tr>
<tr>
<td>Prioritise yellow? = Binomial formula</td>
<td>Y&gt;B = award 1 point for each task Y&lt;B = award 1 point for each task upon which all small Y clusters full</td>
</tr>
<tr>
<td>Strategic Performance Score</td>
<td>Score out of 18</td>
</tr>
<tr>
<td>Error score</td>
<td>score 1 negative point for each task on which an item is placed in the wrong container</td>
</tr>
<tr>
<td>Rule break score</td>
<td>score 1 negative point for each task on which a child breaks the one-by-one rule</td>
</tr>
<tr>
<td>Penalty Performance Score</td>
<td>Score 0 to -6</td>
</tr>
<tr>
<td>Number of task switches</td>
<td>0-?</td>
</tr>
<tr>
<td>Task switch score</td>
<td>switches &lt;3 and &gt; group defined upper limit, score -2</td>
</tr>
<tr>
<td></td>
<td>switches &gt;3 and &lt; group defined upper limit, score +2</td>
</tr>
<tr>
<td>Composite Multitask Performance Score</td>
<td>Score 0 to 20</td>
</tr>
</tbody>
</table>

**[5] Recount**

The recount score assesses the child’s ability to monitor what they achieved during performance on the multitask paradigm. Points are awarded for correct recount of the number of tasks performed (2 points for each task spontaneously mentioned, 1 point for each task mentioned with prompting) and for correct recount of the order in which tasks were performed (3 points where order of recount matches order of
performance, points are subtracted for each discrepancy between the order in which tasks were recounted versus the order in which they were performed, if no performance order is specified during recount but all tasks are indicated, no points are subtracted). The recount variable has a minimum of 0 and a maximum of 9 points and is summarised in Table 4.11.

<table>
<thead>
<tr>
<th>Recount Variable</th>
<th>Points Awarded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recount task</td>
<td>2 points for each unprompted task recounted</td>
</tr>
<tr>
<td></td>
<td>1 point for each prompted task recounted</td>
</tr>
<tr>
<td>Recount order</td>
<td>3 points where recount order matches performance order</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for each task in which recount order does not match performance order</td>
</tr>
</tbody>
</table>

| Recount Score    | Score 0 to 9                                                                  |

4.4.4 What the Battersea Multitask Paradigm measures

Our multitask paradigm taps into a set of cognitive processes that combine to enable individuals to organise future behaviour. Knowledge of the rules governing performance relies on retrospective mnemonic processes (rule learning and rule memory). Once the individual has understood the parameters of the situation and the goals of the task they formulate a plan of how to perform the paradigm; this planning relies on executive planning skills (plan). During the plan a number of intention markers/ prospective delayed intentions are generated, the main focus of these are intentions to switch between multiple tasks, which must be formed and delayed until they are activated later (they cannot be continuously rehearsed due to attention to the current task). When the individual performs the multitask their ability to implement these delayed intentions is assessed by evaluating how well they follow their plan (plan follow) and how effectively they switch between tasks (perform - switch). Self-initiated task switching is dependent upon prospective memory (the initiation and execution of delayed intentions), which is in turn influenced by executive processes such as cognitive flexibility (to switch attention from one task to another) and inhibitory functions (to inhibit attention from the ongoing task to attend to the prospective task). Our multitasking paradigm also taps into other executive functions including the individual's ability to strategically apply the rules of the paradigm to gain points (strategic performance).
and the ability to monitor ongoing performance by inhibiting error making (performance errors) or rule breaking (performance rule break) and being able to recount what was achieved post performance (recount). In line with models of prospective memory all this processing is constrained by the capacity of working memory. The Battersea Multitask Paradigm enables us to investigate the complex and combined set of processes underlying the organisation of future actions in everyday life.

### 4.5 Children’s multitask paradigms

When we designed our children's multitask paradigm we were not aware of any other multitask paradigms designed for use with children. Since then however, three multitask paradigms have been published which have been designed for children. Below we review these paradigms and highlight how they meet many of the characteristics of multitask situations. We then compare them to our children's multitask paradigm. These children's multitask paradigms are summarised in Table 4.12.

We evaluate these children’s multitask paradigms according to the same four key areas that we used to evaluate adult multitask paradigms. These are:

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Multiple tasks</td>
<td>• Tasks must be attempted within a limited period of time</td>
</tr>
<tr>
<td>• Tasks of varying characteristics</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rules</th>
<th>Interleave/ Switch</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Number of rules. These may be task specific (apply to one task) or task general (apply to all tasks).</td>
<td>• Performance on these tasks needs to be interleaved in order to be time effective.</td>
</tr>
<tr>
<td>• No immediate feedback is provided when participants break these rules, therefore the individual determines their own level of successful performance</td>
<td>• Participants are encouraged to switch between tasks via rules or characteristics of the tasks themselves. This switching requires the creation and implementation of delayed intentions.</td>
</tr>
<tr>
<td></td>
<td>• Open ended tasks encourage the participant to switch to another task</td>
</tr>
<tr>
<td>Multitask paradigm</td>
<td>Tasks</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------</td>
</tr>
<tr>
<td><strong>SPT Six Parts Test (Emslie et al., 2003)</strong></td>
<td>Six tasks 2 of each type - Arithmetic (1 &amp; 2) - Picture naming (1 &amp; 2) - Object sorting (1 &amp; 2)</td>
</tr>
<tr>
<td><strong>HEXE Computer Multitask Paradigm (Martin &amp; Kliegel, 2003)</strong></td>
<td>Four tasks 2 of each type: - Arithmetic (A &amp; B) - Picture naming (A &amp; B)</td>
</tr>
<tr>
<td><strong>C-SET Children's Six Elements Test (Siklos &amp; Kerns, 2004)</strong></td>
<td>Six tasks 3 red, 3 blue: - Construct lego - Solve mazes - Hidden object search - Tell a pirate story - Dinosaur puzzle - Spot the mistake</td>
</tr>
<tr>
<td><strong>Battersea Multitask Paradigm</strong></td>
<td>Three tasks - Bead sorting - Caterpillar colouring - Counter placing</td>
</tr>
<tr>
<td></td>
<td><strong>Number of tasks</strong></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
4.5.1 Review of other multitask paradigms designed for children

The Six Parts Test (SPT) forms part of the children’s assessment of the dysexecutive syndrome test battery (Emslie et al., 2003) and is closely modelled on the adult Modified Six Elements Test. The test has six tasks divided into three pairs which are colour coded (red, green and blue). There are two arithmetic tasks (green 1 and green 2) which begin with simple counting tasks, two picture naming tasks (blue 1 and blue 2) which involve naming line drawings of everyday objects, e.g., a chair or a ball, and two object sorting tasks (red 1 and red 2) which involve sorting out nuts and beads from a mixture of similar objects. On the arithmetic task and the picture naming task children must write down their answers, although the accuracy of these is not important. The tasks are open ended and can realistically only be performed one at a time. There is a 5 minute time limit to perform the SPT, depicted by a timer which is visible to the child at all times rather than under cover as in many adult tests.

Performance is governed by two rules: children should attempt part of all six tasks before the time is over, and they should not attempt two parts of the same colour one after the other. Interleaving of tasks is achieved by requiring children to perform all six tasks within a limited time, and by the task order rule. As in adult multitasks, task switching is a measure of the implementation of delayed intentions and performance on one task must be interrupted in order to attempt another task. Children determine for themselves what constitutes adequate performance as there are no clear indications of performance goals, beyond the requirements outlined by the rules. No feedback is given during performance when a child breaks the order rule.

Performance on the SPT is scored to capture how successfully children are able to co-ordinate performance on multiple tasks, and whether they adopt a strategy to aid their performance. The number of tasks attempted is scored, plus whether the child adopted an obvious strategy to switch between tasks obeying the order rule (for example: red – blue – green – red – blue – green), and to attempt all six tasks (by allowing a set amount of time on each task, or performing a set number of items on each task before switching). Children are penalised each time they break the task order rule. This method of scoring captures switching and strategic aspects of children’s multitask performance and has proven sensitive to developmental differences in children aged 8 through to 16-years (Emslie, 2004).
Chapter 4: Developing a children’s multitask paradigm

The HEXE multitask paradigm for children (Martin & Kliegel, 2003) is a computer paradigm very similar to the adult HEXE presented earlier, except it has fewer tasks. There are 4 tasks which must be performed in a 6 minute time limit. Tasks are colour coded into two blue picture naming tasks (part 1 and 2) and two green arithmetic tasks (part 1 and 2). Performance is governed by two simple rules, children must perform all four parts before the time runs out, and children cannot perform two parts of the same task one after the other. Again these two rules ensure that task performance is interleaved rather than sequential. The tasks are open ended so that performance on one task must be interrupted to switch to another task, task switching is taken as a measure of the execution of a delayed intention; hence as a fairly direct measure of prospective memory. The computer limits the tasks to being performed one by one and gives no feedback where a child breaks the rules. Time is depicted by a time bar at the top of the screen that gradually fills up. Each child determines their own performance level as it is not explicitly stated how to go about performing all subtasks. Performance is scored as the number of times a child breaks the order rule and the number of tasks attempted. Using this scoring system significant age differences are found in children aged 6 to 11 years of age (Martin & Kliegel, 2003).

The Children’s Six Elements Test, C-SET (Siklos & Kerns, 2004) was designed as a more attractive and developmentally appropriate version of the Six Elements Test. This test has 6 individual tasks of varying characteristics. A ‘lego’ task in which the child is given instructions to build a small catapult, a hidden pictures task in which the child must search for and circle objects in a series of pictures. A ‘pirate scene’ story telling task in which the child uses a metallic picture board and figures to tell the experimenter a story about pirates. A mazes task where the child attempts to solve mazes of increasing levels of difficulty, a puzzle task in which the child fits together a jigsaw of a dinosaur and a ‘spot the mistake’ task in which the child circles silly elements in drawings. The tasks are colour coded, 3 tasks are placed side by side in red boxes and three side by side in blue boxes. There is a 10 minute time limit to perform the C-SET displayed as a countdown timer on a computer screen which remains visible to the children at all times.

Task performance is governed by 3 rules: children must attempt all six tasks in 10 minutes, it is not possible to complete all the tasks within the time allowed and most children get the most points for trying all six, they cannot try two tasks of the same colour after one another. These rules ensure that task
performance is **interleaved**, and the instruction that children cannot complete all the tasks ensures that they should interrupt ongoing task performance to perform another task. Not all the tasks are open-ended, a fact that may discourage switching, although successful performance of all 6 tasks does require interrupting ongoing performance therefore relying upon the implementation of a delayed intention to switch. Tasks can realistically only be attempted one at a time, and children set their own performance level, for example the complexity of the pirate story they tell. No feedback is given during task performance and performance on individual tasks is not scored. Performance is scored as the number of tasks the child attempts and the number of times they break the order rule. The C-SET has been administered to a small group of children aged 7 to 13 years who were acting as controls to a group of children diagnosed with attention deficit hyperactivity disorder (ADHD). No age related performance scores are reported, however control children performed an average of 5.62 tasks and break the order rule very infrequently (Siklos & Kerns, 2004).

### 4.5.2 Comparing the Battersea Multitask Paradigm to other children’s multitask paradigms

It is interesting to observe that the three multitask paradigms discussed above have largely focused on having multiple tasks governed by few rules. The SPT has 6 tasks and 2 rules, the C-SET has 6 tasks and 3 rules and the HEXE has 4 tasks and 2 rules. In contrast our Battersea Multitask Paradigm has fewer tasks and more rules. A similar contrast can be drawn in the adult literature between multitask paradigms such as the Six Elements Test and the Greenwich Multitask Test. The number of tasks interacts with the number of rules in any multitask situation. In our Battersea Multitask Paradigm fewer subtasks necessitated a greater number of rules to encourage more switching between tasks. For the most part, the individual tasks in these other children’s multitask tests were designed to be child friendly and simple, they also focused on abilities such as colour matching, drawing, and object sorting. The majority of these tests were open-ended like ours, although some of the tasks in the C-SET may not be (e.g., the object construction task or the puzzle task).

Equally interesting are the different methods of scoring performance adopted by these children’s multitask tests. The scoring system in the HEXE paradigm focuses on the number of tasks attempted and the number of times the ‘task order’ rule is broken. C-SET performance is also scored in this way, although in addition the number of times the child checks the clock is recorded as a measure of time-
Chapter 4: Developing a children's multitask paradigm

based strategy use. The SPT has the most sophisticated scoring system, measuring whether children adopt strategies (time based or task item based) to successfully perform all six subtasks. Our scoring system is more complex than all these other scoring systems, as we measure a variety of cognitive processes which may underlie multitasking including retrospective memory, planning and prospective memory.

Like other children's multitask paradigms we assess the child's ability to switch fluently between multiple interleaved tasks and their ability not to make errors or break rules. However, we also assess how well children are able to strategically apply rules to enhance task performance. Other children's multitask paradigms focus on successful switching between multiple tasks but do not measure how well children perform on the individual tasks themselves. In everyday life it is important that we not only perform the tasks we intend to perform, but that we perform them effectively. Our paradigm captures this aspect of multitask performance.

4.6 Chapter summary

In this chapter we introduced the Battersea Multitask Paradigm. We considered the elements involved in multitasking and analysed the extent to which existing adult multitask paradigms incorporate these elements. From this analysis we derived several important elements to incorporate into our children's multitask paradigm. We then developed and piloted three versions before finalising our children's Battersea Multitask Paradigm. We have also developed a fixed administration and scoring system for our multitask paradigm. Finally we compared our children's multitask paradigm to other multitask tests that have recently been designed for use with children. We concluded that our paradigm has different strengths, as it enables us to measure the overall ability to organise future behaviour, and to evaluate the various cognitive processes called upon in a multitask situation including retrospective memory, planning and prospective memory.
The organisation of future behaviour is a skill relevant to everyday life and independent living (Kliegel & Martin, 2003; Ward et al., 2004). The aim of this study was to seek information about how children develop the skills necessary to organise their future behaviour. This was achieved by using multitasking as a methodological tool to investigate the cognitive abilities underlying the organisation of future behaviour in children. We investigate multitasking in children aged 6 to 10-years of age. It has been suggested that the ability to organise future actions becomes increasingly necessary as children gain independence when they start school (Meacham & Colombo, 1980), and research has indicated that the cognitive processes underlying the organisation of future behaviour undergo significant development in middle childhood from age 6 to 12 years of age. Consequently, there is good reason to expect developmental changes in the organisation of future behaviour in children 6 to 10 years of age.

5.1 Introduction

In previous chapters we discussed the validity of multitasking as methodology that taps into the cognitive processes underlying the organisation of future behaviour in everyday life (Alderman et al., 2003; Burgess et al., 1998, 2000; Shallice & Burgess, 1991; Wilson et al., 1998). We highlighted how the development of future organisation skills in childhood has not been researched as much as it has in
adulthood (Haith et al., 1994), although research to date broadly supports the development of the skills underlying the organisation of future action in childhood (e.g., Haith et al., 1994; Martin & Kliegel, 2003). We outlined how we developed a multitasking paradigm for children which meets many of the parameters of multitasking in everyday situations, such as performing multiple, interleaved, open-ended tasks in circumstances where feedback is not immediate and performance goals are largely self-determined. Multitasking enables investigation of a number of interacting cognitive processes within a whole, complex, realistic episode. The administration procedure of the Battersea Multitask Paradigm enables us to investigate the development of children's ability to organise future behaviour and to assess a number of cognitive processes underlying this skill. We anticipate developmental differences in the overall ability to organise future actions in children aged 6 to 10 years, on the basis of children's growing independence and their emerging capacity to organise themselves as autonomous agents in their everyday environments (Meacham & Colombo, 1980; Winograd, 1988). Using our paradigm we can also investigate developmental differences in the cognitive processes underlying the ability to organise future behaviour. Below we formulate hypotheses about how children will score on variables generated by our Battersea Multitask Paradigm.

The paradigm taps into retrospective memory processes via two variables, rule learning and rule memory. We do not anticipate significant group differences in scores on these variables, not because retrospective memory does not develop across the 6 to 10 year age range, but because we intend to ensure that children understand the rules of the paradigm prior to performance. The rules governing multitasking ought to be simple enough for children of different ages to learn and retain. If there are differences in children's knowledge of the task, measures taken subsequent to rule-learning (such as planning and performance measures) may be compromised as any age group differences observed may simply be the product of younger children being less informed about what it is they are supposed to be doing. In this study no age group differences in retrospective memory are anticipated as we designed our multitask paradigm to be as simple as possible with a low memory load.

Children's planning skills are measured by the 'plan' variable in the Battersea Multitask Paradigm and we expect scores on this variable to be significantly different between age groups. This is due to literature supporting the development of planning abilities across the 6 to 10 year age range (Anderson,
Developmental differences in children's ability to follow through an intended plan have been found between 6 and 8-year old children (Klahr et al., 1993). Furthermore, the implementation of a plan is dependent on prospective memory and research indicates that prospective memory develops in childhood across the 6 to 10 year age range (Beal, 1988; Brandimonte & Passolunghi, 1994; Ceci et al., 1988; Kerns, 2000; Meacham & Colombo, 1980; Nigro et al., 2002). Therefore we anticipate that age group differences in plan following skills will also be found.

The multitask performance variable is composed of a number of scores representing various underlying cognitive processes. Two previous studies investigating the development of overall multitasking skills in children have reported significant development of these skills in children between the ages of 6 to 16 years (Emslie et al., 2003; Martin & Kliegel, 2003). We predict similar developmental differences for children aged 6 to 10 years of age performing our multitasking paradigm, and we are able to investigate in greater depth which of the cognitive processes underlying multitasking performance may develop. Switching between multiple tasks relies on prospective memory (as switching is dependent on the delayed implementation of a previously generated intention to switch), and on executive functions including cognitive flexibility and inhibitory control. Prospective memory skills develop over the 6 to 10 year period (Brandimonte & Passolunghi, 1994; Kerns, 2000; Meacham & Colombo, 1980). Likewise studies investigating the development of cognitive flexibility and inhibitory control evidence significant developmental gains in these abilities over this age range (Anderson, 1998, 2002; Chelune & Baer, 1986; Levin et al., 1991; Welsh et al., 1991). The strategic performance score taps into strategy use, an executive function that has been shown to have a period of significant development in children from age 6 upwards (Anderson, 1998; Klahr et al., 1993; Levin et al., 1991; Welsh et al., 1991). As such, we expect scores on this aspect of multitasking to be significantly different between children aged 6 to 10 years of age. Children's ability to monitor their performance during multitasking is assessed by measuring rule breaking and error making behaviours (aspects of performance for which participants are penalised). Extreme rule breaking behaviour characterises the performance of patients with frontal lobe damage during multitasking and has been attributed to a failure of executive control (Shallice & Burgess, 1991); we hypothesised that children, in whom executive control is developing, will
evidence parallel developmental gains in their ability to inhibit rule breaking and error making behaviour.

Finally, the recount variable assesses children's ability to evaluate their own performance and monitor progress towards goals. Recount taps into the updating function of prospective remembering, when a previously generated intention has been activated and the intended action performed, this information must be updated to prevent the action being performed again unnecessarily. Comparatively little research has investigated the development of this performance monitoring ability in childhood, so there is little direct evidence to base a hypothesis on. However, in the prospective memory literature children's ability to monitor their external and internal environments for prospective memory cues does show developmental differences between young childhood and adolescence (Ceci et al., 1988; Kerns, 2000; Passolunghui et al., 1995). On the basis of this research we predict that age group differences on the recount variable will be observed.

In sum, the cognitive processes underlying the organisation of future behaviour develop across middle childhood. The aim of this study was to use an adapted version of an adult multitask paradigm to map the development of the organisation of future behaviour in children aged 6 to 10 years of age. Our children's multitask paradigm consists of three tasks governed by four rules. The three tasks are simple to perform in themselves and their content appropriate for children as young as 6 years of age. The four rules governing task performance are generalised across all tasks to reduce complexity. The time allowed for task performance is 3 minutes. Switching between tasks is self initiated and internally generated, although salient external cues may influence switch performance, such as the visibility of the sand timer and the other tasks. It is most strategically advantageous to switch between tasks a number of times.
5.2 Aims & hypotheses

Developmental differences in the overall organisation of future behaviour are anticipated (representing scores on most multitask variables, most particularly the multitask performance composite), as are changes in some of the cognitive skills underlying this broader ability. These hypotheses are summarised in Table 5.1.

Table 5-1: Predicted age group differences on multitasking variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group Differences?</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule Learn &amp; Memory</td>
<td>No</td>
<td>Retrospective memory components of multitasking: as the paradigm is designed to be equally simple for children of all ages to understand.</td>
</tr>
<tr>
<td>Plan</td>
<td>Yes</td>
<td>Children’s planning skills develop between 6 and 10-years of age. Older children will form more complex plans (complexity being measured by the number of tasks included in the plan) and more strategic plans than younger children (i.e., plans that use the rules to maximise points).</td>
</tr>
<tr>
<td>Plan Follow</td>
<td>Yes</td>
<td>Older children will not only plan better than younger children will, they will also be more likely to implement the plan they have made.</td>
</tr>
<tr>
<td>Multitask Performance</td>
<td>Yes</td>
<td>Older children will be more able to multitask than younger children (measured by number of tasks attempted), and more efficient multitaskers than younger children (measured by overall multitask performance).</td>
</tr>
<tr>
<td>Composite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task Switching</td>
<td>Yes</td>
<td>As children’s prospective memory develops they will be more able to self initiate and execute delayed intentions and more able to switch efficiently between tasks. Younger children are expected to be relatively inefficient task switchers, with performance on this measure improving with age as children’s prospective memory develops.</td>
</tr>
<tr>
<td>Strategic Performance</td>
<td>Yes</td>
<td>Children’s ability to strategically apply the rules of the multitask paradigm may develop as their ability to form strategies does.</td>
</tr>
<tr>
<td>Rule Breaking</td>
<td>Yes</td>
<td>Rule breaking is expected to decline with age, as children become better at inhibiting the temptation to break the rules.</td>
</tr>
<tr>
<td>Performance Errors</td>
<td>Yes</td>
<td>Fewer performance errors will be made by older children whose ability to monitor ongoing performance is better developed.</td>
</tr>
<tr>
<td>Recount</td>
<td>Yes</td>
<td>Children’s ability to monitor what they achieved during performance will improve with age in line with developments in prospective memory and executive functions.</td>
</tr>
</tbody>
</table>
5.3 Method

5.3.1 Study design
The design of the study is a cross-sectional, between-groups design. Three groups of children were recruited to the study: a group of 6-year old children, a group of 8-year old children and a group of 10-year old children.

5.3.2 Ethical considerations
This study was approved by the University College London Ethics Committee A for Research Involving Human Participants, and received reciprocal approval from the Great Ormond Street Hospital Ethics Committee. Written parental consent was obtained for each child who participated. In addition specific permission to video the test session was obtained. Parents were given opportunities to ask questions about the study; the researcher was available in school at a specified date and time and the researcher’s contact telephone number and email address were included on the study information sheet. Verbal assent was sought from each participating child, as was permission to video the session. No child whose parents had consented objected to participating in the study. Children received a certificate and a small reward for participating in the study (a Great Ormond Street Pencil). School classes received book tokens (typically £15) as a way of thanking them for their help.

5.3.3 Participants

Recruitment
Children were recruited from three mainstream primary schools within a London local education authority area (Wandsworth Borough). All schools involved performed at the national average on standardised tests of key educational subjects. Head Teachers were approached via letter and asked to give permission for their school to participate in the study, this letter was typically followed up by a phone call and an appointment to visit the head to discuss the study further. Once the Head Teacher’s permission had been obtained, the researcher met class teachers to talk about the study and give them recruitment letters and consent forms. Letters were sent home with all children in participating classes;
in the letter parents were provided with information about the study and given the opportunity to ask questions. A consent form was also enclosed which parents were asked to return to the class teacher. Once letters had been returned, suitable testing times were agreed between the researcher and the class teacher.

**Response rates**

Three schools participated in the study. Across the 3 schools, 3 classes for each age group were approached, with between 30 and 35 children in each class. Of the 100 letters sent home to parents of 6-year-old children, 51 were returned of which 46 granted consent. Forty-three of these children were assessed (3 children were absent from school at time of testing). Of the 100 letters sent home to parents of 8-year-old children, 43 were returned of which 39 granted consent. Thirty-seven of these children were assessed (2 children were absent from school at time of testing). Of the 100 letters sent home to parents of 10-year-old children, 41 were returned of which 37 granted consent. Thirty-six of these children were tested (1 child was absent from school at time of testing).

5.3.4 Procedure

**Test environment**

Test sessions were conducted in a quiet room in each school. The researcher collected and returned each child to and from class. During the session the child was seated at a table opposite the researcher. As the procedure was videotaped for analysis, a camcorder fixed on a tripod was placed behind the researcher (to one side) and focused on the child’s head and hands with a view of all three tasks. The three tasks used in the paradigm were laid out horizontally on the table between the child and the researcher. The arrangement of the 3 tasks on the table was counterbalanced between children, with 6 possible arrangements of the 3 tasks. Children sat in the same position whilst the WISC-III sub tests were administered, performance on these tasks was not videotaped.

**Test administration**

The order of task presentation was invariant across all participating children: multitask paradigm, WISC-III block design and WISC-III vocabulary. The total testing session took approximately 20-25
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minutes. At the end of the session the child was thanked, given a certificate and small prize and accompanied back to the classroom.

5.3.5 Measures

**Battersea Multitask Paradigm**

The administration of the multitask paradigm followed a set procedure, outlined earlier in Chapter 4 and more fully in Appendix 1. First the child is taught the 3 tasks using practice materials. Once the researcher is satisfied that the child understands how to ‘play’ the ‘games,’ the child is guided through the six administration steps of the multitask paradigm. (1) Learn the 4 rules of the paradigm. (2) Form a verbal plan indicating how the child intends to perform the paradigm. (3) Perform the paradigm. (4) Plan follow: how well the child followed their plan is assessed post-performance. (5) The child recounts what they have achieved during performance. (6) Finally the child’s memory for the rules is assessed once again. The entire procedure is videotaped for analysis in addition to which the researcher completes a score sheet during task administration. The Battersea Multitask Paradigm generates six key variables: rule learn, plan, plan follow, performance, recount and rule memory. In addition, multitask performance is broken down into switching, strategic performance and rule breaking/ error making. Scores are awarded for each of these variables (as outlined in Chapter 4 and Appendix 2).

**Wechsler Intelligence Scale for Children UK 3rd Edition (WISC III) – Two Subtests**

We used two subtests of the WISC-IIIUK (Weschler, 1992) to assess whether our participant groups were broadly equivalent in terms of intellectual ability. Our multitasking paradigm is a new and complex cognitive measure and we wanted to be confident that group differences in performance could not be accounted for by group differences in intellectual ability. In the block design subtest the child is given three dimensional blocks composed of two colours which are used to reproduce a two dimensional abstract pattern and in the vocabulary subtest a series of words is presented orally which the child has to define. Scores on each subtest are converted to age-appropriate standard scores ranging from 1-19, with a mean of 10 and a standard deviation of 1.5. Materials consisted of the WISC IIIUK stimuli booklet, blocks, and scoring sheets. Administration of the subtasks followed WISC IIIUK guidelines.
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5.4 Results

5.4.1 Exploration of the data

Sample characteristics

108 children participated in this study: a 6-year old group, an 8-year old group and a 10-year old group. There were approximately equal numbers of boys and girls in each age group (Table 5.2). Distribution of ethnic diversity was also broadly similar: 6-year olds (24 Caucasian, 10 Afro-Caribbean, 2 Asian, 2 Chinese); 8-year olds (24 Caucasian, 4 Afro-Caribbean, 4 Asian, 1 Chinese and 1 Mixed Race); 10-year olds (21 Caucasian, 9 Afro-Caribbean, 3 Asian and 2 Mixed Race).

Table 5-2: Sample Characteristics

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Age (years, months)</th>
<th>SD (months)</th>
<th>Range (months)</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-years (38)</td>
<td>6y 3m</td>
<td>3.17</td>
<td>68 - 80</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>8-years (35)</td>
<td>8y 2m</td>
<td>3.35</td>
<td>92-104</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>10-years (35)</td>
<td>10y 8m</td>
<td>3.71</td>
<td>122-134</td>
<td>19</td>
<td>16</td>
</tr>
</tbody>
</table>

As outlined earlier, estimates of verbal and non-verbal ability were obtained for each child using the vocabulary and block-design sub tests of the WISC-III<sup>UK</sup>, scaled scores detailed in Table 5.3. Means were normally distributed for all age groups. One way analysis of variance revealed a significant group difference in our verbal IQ measure \( F (2,105) = 8.42, p < .001 \) but not our performance IQ measure \( F (2, 105) = .33, \text{NS.} \). Post hoc Tukey's Honestly Significant Difference (HSD) tests revealed that this significant difference was between the 6-year olds verbal IQ and the 8-year olds verbal IQ \( (p < .05) \).

Table 5-3: WISC-III<sup>UK</sup> vocabulary and block-design scaled scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Verbal IQ Measure Vocabulary Test (mean scaled score = 10)</th>
<th>Performance IQ Measure Block Design Test (mean scaled score = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>6-years (38)</td>
<td>9.31</td>
<td>2.73</td>
</tr>
<tr>
<td>8-years (35)</td>
<td>12.70</td>
<td>4.20</td>
</tr>
<tr>
<td>10-years (35)</td>
<td>11.03</td>
<td>3.53</td>
</tr>
</tbody>
</table>
Cases excluded from analyses
A number of children were excluded from the analyses as they failed to complete the multitask. Four 6-year old children were excluded as they had spoken English as a second language (ESL) and were unable to follow instructions during task training; one further 6-year old was excluded who had severe learning difficulties. Two 8-year olds and one 10-year old with ESL were also excluded as they lacked satisfactory language skills to perform the paradigm. All children who were excluded from the analyses were allowed to 'play' the game under timed conditions and received a certificate and a prize like other participants.

Parametric or non-parametric analyses?
Parametric statistical analyses such as Analysis of Variance (ANOVA) rely on the assumption of homogeneity of variance. Examination of the standard deviations of the 6 key variables generated by the multitask paradigm revealed greater variance in the performance of younger children than older children. Further investigation revealed that group comparisons on some variables fail Levene’s test for homogeneity of variance, thus violating the assumption of equal variance. Non-parametric methods do not presume homogeneity of variance. For all group comparisons where equal variance could not be assumed, non-parametric Mann Whitney U tests were calculated. The results obtained were identical to those obtained by their parametric equivalents. In reality, ANOVA is a relatively robust statistical test which can withstand some violation of its underlying assumptions (Gravetter & Wallnau, 1992). For the sake of consistency and parsimony, all analyses reported below will be parametric analyses.

5.4.2 Group comparisons on multitask variables
Figure 5.1 below illustrates the children’s scores on each of the 6 key variables generated on the Battersea Multitask Paradigm. These scores are described as percentages to enable comparisons between variables scored on different scales. Examination of the variables in Figure 5.1 indicates patterns of group differences across all aspects of multitasking, reflecting the development of the ability to organise future behaviour in children aged between 6 and 10-years. These group differences are considered below.
[1] Rule Learning and Rule Memory

Participant's knowledge of the rules of the paradigm was assessed by two scores, a rule learning score (obtained prior to multitask performance) and a rule memory score (obtained after multitask performance). The mean rule learning and rule memory scores for participants in each age group are presented in Table 5.4.

Table 5.4: Rule learning and rule memory scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Rule learning (score out of 18) Mean (SD)</th>
<th>Rule memory (score out of 18) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-years (38)</td>
<td>11.37 (3.11)</td>
<td>11.40 (2.91)</td>
</tr>
<tr>
<td>8-years (35)</td>
<td>15.20 (2.23)</td>
<td>15.00 (2.15)</td>
</tr>
<tr>
<td>10-years (35)</td>
<td>15.80 (1.57)</td>
<td>15.60 (1.67)</td>
</tr>
</tbody>
</table>
We had not anticipated age group differences on rule learning and memory variables, given that the four rules of the game were explicated to children a number of times prior to performance and that the paradigm had been designed to load upon retrospective memory as little as possible. However, contrary to expectations, 6-year olds were less able to learn and remember the rules of the paradigm than were 8 or 10-year olds. Analysis of variance revealed a significant main effect of group for rule learning \([F (2, 105) = 36.60, p< .001]\) and rule memory \([F (2, 105) = 35.60, p< .001]\). Follow up Tukey HSD tests indicated that 6-year olds overall rule learning and memory was significantly different from that of 8-year olds \((p < .001)\) and 10-year olds \((p < .001)\). There were no significant differences between the ability of 8 and 10-year old children to lean and retain the rules of the paradigm.

Rule learning and rule memory are measured by both free recall and cued recall, representing two ways of assessing encoding of the to-be-remembered information. Free recall of the rules requires participants to generate the rules spontaneously, whereas cued recall requires them to answer a series of questions about the rules of the paradigm. We speculated that free recall might be more challenging than cued recall, and wondered whether group differences in rule learning and memory could be explained by 6-year-olds simply being less able to spontaneously recall the rules of the paradigm. Group mean scores for free and cued rule learning and memory are detailed in Table 5.5.

<table>
<thead>
<tr>
<th>Age</th>
<th>Rule Learning</th>
<th>Rule Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Free Recall (0-8)</td>
<td>Cued Recall (0-10)</td>
</tr>
<tr>
<td>Group (N)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>6-yrs (38)</td>
<td>3.61 (2.11)</td>
<td>7.91 (1.50)</td>
</tr>
<tr>
<td>8-yrs (35)</td>
<td>5.91 (1.82)</td>
<td>9.31 (0.82)</td>
</tr>
<tr>
<td>10-yrs (35)</td>
<td>6.54 (1.27)</td>
<td>9.26 (0.82)</td>
</tr>
</tbody>
</table>

Analysis of free recall scores revealed a main effect of age for both free recall rule learning \([F (2, 105) = 28.72, p< .001]\) and free recall rule memory \([F (2, 105) = 31.50, p< .001]\). Once again, follow up Tukey HSD tests indicated that 6-year olds were significantly poorer at spontaneously reproducing the rules of the paradigm than were 8 \((p < .001)\) or 10-year olds \((p < .001)\). In fact 6-year olds scored an
average of only 40% of available points. In contrast 8 and 10-year olds did not differ significantly from one another in their ability to spontaneously recall the rules of the paradigm. Examination of cued recall of the rules also showed a significant main effect of age group for both cued rule learning \[F (2, 105) = 22.21, p < .001\] and cued rule memory \[F (2, 105) = 14.32, p < .001\]. Post hoc Tukey HSD analyses revealed that although 6-year olds fared better when their rule-knowledge was tested via cued questions, remembering on average 80% of the rules, this was still significantly different from the performance of 8 \(p < .001\) and 10-year olds \(p < .001\) who remembered on average 90% of the rules upon cued questioning.

It is likely that 6-year old children’s knowledge of the rules was qualitatively different from that of older children. This unexpected result has implications for interpreting the scores of 6-year olds on other variables measured, as one might argue that if 6-year olds do not have an adequate representation of what they are supposed to be doing, group comparisons on other variables such as planning and performance may be compromised. Group differences on other multitask variables will be interpreted with caution in view of this caveat.

[2] Planning

We hypothesised that children’s ability to plan how they will perform the multitask paradigm will improve with age, to test this hypothesis age group scores on the plan variable were examined. Mean scores are displayed in Table 5.6 and suggest a pattern of developmental differences in planning performance across all three age groups. Analysis of variance indicated a significant main effect of group \[F (2, 105) = 22.42, p < .001\]. Follow up Tukey HSD tests indicated that the significant differences were between the two younger groups and the 10-year old children: 6-years < 10-years \(p < .001\), 8-years < 10-years \(p < .001\). Older children produced significantly more detailed plans than their younger counterparts, yet even older children did not score at ceiling on this measure.
Two specific predictions were made about age-group differences in planning. The first was that younger children would form less complex plans than older children, this hypothesis was tested by examining the number of tasks children planned to perform. During task administration children whose plan did not at first include an intention to attempt all three tasks were prompted to do so, and multitask performance did not begin until this had been achieved. Younger children needed more prompts than older children, indicating that their plans were less complex, the number of prompts required by children in each age group is illustrated in Figure 5.2.

Figure 5-2: Complexity of plans (number of prompts required per age group, in %)
Figure 5.2 demonstrates that 6 and 8-year old children formed more basic plans (often requiring prompting from the researcher to include all three tasks in their plan) than 10-year olds, 90% of whom spontaneously planned to perform all three tasks. This indicates a clear developmental progression as children move from plans in which inclusion of all three tasks has to be prompted, to plans where they spontaneously plan to perform all 3 tasks.

The second prediction was that older children would form more strategic plans than younger children. A strategic plan is a plan that involves using the rules to score more points. As we discussed in Chapter 4, the planning score is derived by awarding points when a strategic intention to use a rule to gain points is included in the child’s plan. Two aspects of a child’s plan are considered, planning to prioritise yellow items (worth more points than blue) and planning to fill clusters of items (to earn bonus points). Group scores on these aspects of planning are presented in Table 5.7.

Table 5-7: % and number of children whose plan included strategic intentions

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>% whose plan included any of these strategic elements (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prioritise yellow</td>
</tr>
<tr>
<td>6-years (38)</td>
<td>23.7 (9)</td>
</tr>
<tr>
<td>8-years (35)</td>
<td>22.9 (8)</td>
</tr>
<tr>
<td>10-years (35)</td>
<td>62.7 (23)</td>
</tr>
</tbody>
</table>

Analysis of variance indicated a main effect of age group on strategic planning for both prioritising yellow items \([F (2, 105) = 11.12, p < .001]\) and for planning to fill clusters of items \([F (2, 105) = 9.76, p < .001]\). Follow up Tukey HSD tests indicate significant group differences are between the 10-year olds and both groups of younger children for prioritising yellow items \((p < .001)\) and planning to fill clusters \((p < .01)\). There were no significant differences between the 6 and 8-year olds on either of these measures. As predicted older children are significantly more able to form strategic plans; over 60% of 10-year olds included such intentions in their plans, compared with less than 25% of 6 and 8-year olds.

In conclusion, age group differences in planning are between 6 and 8-year old versus 10-year old children. Differences between 6 and 10-year old children should be interpreted with caution given the
group differences in rule learning and memory that we reporter earlier. The differences observed between the 8 and 10-year old groups can be interpreted with confidence given the comparable ability of these groups to learn and retain the rules governing the multitask paradigm. Younger children make more basic plans and require a greater amount of encouragement to do so, whilst older children's plans are more complex and strategic.

[3] Plan Follow

The plan follow variable measures the extent to which a participant has 'stuck to' or followed their original plan, and is interpreted as a measure of the prospective implementation of a previous set of intentions. The plan follow score is calculated as the child's original plan minus any deviations from this plan (deviations made during performance). We hypothesised that older children would not only form better plans, but that they would also be better at implementing their plans, thus obtaining higher plan following scores. Group mean plan following scores are detailed in Table 5.8.

Table 5-8: Plan following scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Plan following (score out of 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>6-years (38)</td>
<td>4.29 (2.46)</td>
</tr>
<tr>
<td>8-years (35)</td>
<td>5.43 (2.34)</td>
</tr>
<tr>
<td>10-years (35)</td>
<td>8.37 (2.83)</td>
</tr>
</tbody>
</table>

Between groups analysis of variance indicated a main effect of group on plan follow \( [F (2, 105) = 24.56, p < .001] \), post hoc Tukey HSD tests indicated that significant differences are between 6, 8-year olds < 10-year olds \( (p < .001) \). However, recall that we are interested in how well children are able to implement the plan they formed, irrespective of the quality of that plan. We therefore have to factor out group differences in planning in order to investigate group differences in plan implementation. We performed an analysis of co-variance (ANCOVA), co-varying for planning: group differences in plan following remained significant \( [F (2, 107) = 4.05, p < .05] \). Group-by-group ANCOVA's revealed that 6 and 8-year olds are significantly different in their ability to implement plans: \( F (1, 72) = 6.34, p < .05 \) [estimated marginal means 6-years = 4.52 (standard error, SE=.18), 8-years = 5.18 (SE=.19)].
Likewise, 6 and 10-year olds were significantly different from one another: $F(1, 72) = 4.88, p < .05$; [estimated marginal means 6-years = 5.89 (SE=.21), 10-years = 6.63 (SE=.22)]. However 8 and 10-year olds did differ significantly in their ability to implement the plan they had made: $F(1, 69) = .05$, NS, [estimated marginal means 8-years = 6.87 (SE=.20), 10-years = 6.93 (SE=.20)]. Given our reservations about the ability of 6-year old participants to understand the rules governing task performance these results, where 6-year olds differ from the two older groups, must be interpreted with caution.


How well children perform the multitask is representative of their overall ability to organise future behaviour. Group scores for the composite ‘multitask performance’ score are presented in Table 5.9. They demonstrate a clear developmental increase in the overall ability to organise future behaviour, although it should be noted that even the oldest children are still not performing at the maximum level. Analysis of variance revealed a significant main effect of group on overall performance scores [$F(2, 105) = 16.62, p < .001$]. Follow up Tukey HSD tests indicated that 6-year olds overall performance was significantly different from that of 8-year olds ($p < .01$) and 10-year olds ($p < .001$). There was a trend for 8 and 10-year olds scores to be significantly different from one another ($p = .059$).

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Composite Multitask Performance (max 20) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-years (38)</td>
<td>8.16 (5.00)</td>
</tr>
<tr>
<td>8-years (35)</td>
<td>12.11 (5.20)</td>
</tr>
<tr>
<td>10-years (35)</td>
<td>14.90 (4.84)</td>
</tr>
</tbody>
</table>

Table 5-9: Multitask performance scores

We also investigated how many children in each age group attempted all 3 tasks within the time allowed: 23 (60.5%) 6-year olds, 29 (82.9%) 8-year olds and 32 (91.4%) 10-year olds performed all 3 tasks. Age group differences were evaluated using Chi squared analysis: significantly fewer 6-year olds performed all three tasks compared to 8 [$X^2 = 4.43; df = 1; p < .05$] and 10-year olds [$X^2 = 9.40; df = 1; p < .01$]. The difference between the number of tasks performed by 8 and 10-year olds was not
significant \( X^2 = 1.15, \ df = 1, \ NS. \). Six-year olds were less able to perform the requisite 3 tasks than older children, although this pattern of results should be interpreted with caution bearing in mind the unexpected age-related differences in children's ability to learn and retain the rules of the paradigm.

The multitask performance score is a composite score representing scores on a number of aspects of multitask performance. We had anticipated significant group differences on all of these scores including task switching, strategic performance, and aspects of performance which are penalised (error making and rule breaking). Group performance on each of these scores is examined below.

(a) Task switch performance
The switch score represents the number of times a child has spontaneously switched from one task to another during multitask performance. Self-initiated switching represents the implementation of a previously generated intention (to switch) and is considered to be a measure of prospective memory. Switch scores are dichotomously categorised as 'efficient' or 'inefficient.' In order to determine these criteria, the distribution of scores for the entire sample is examined, represented in Figure 5.3.

Figure 5-3: Distribution of number of task switches – all age groups

The dotted lines in Figure 5.3 represent the lower and upper limits of the 'efficient' switch strategy. Outside this area lie the 'inefficient' strategies. As discussed in Chapter 4, the minimum number of
switches considered to be 'efficient' is not 2 switches, but 3 (it takes 2 switches to try all 3 tasks). A child who switches fluently between multiple interleaved tasks must evaluate switching between tasks beyond the basic requirement to perform all three tasks. The upper limit of efficient switching is determined by the switch performance of the whole sample. In the present study this was set at a maximum of 11 switches. Three children switched more than 11 times, this strategy is inefficient as it frequently involves failing to fill a whole cluster prior to moving on to another task. All three children who adopted this over-zealous switching strategy failed to fill clusters before moving onto another. Indeed, the child who switched a frantic 53 times placed only one item on each of the 3 tasks over and over again until the time ran out, not pausing to consider where items were being placed or to finish filling a whole cluster. Having determined the limits for efficient and inefficient task switching, category membership can be compared across the age groups to test the hypothesis that children’s ability to switch more efficiently will improve with age. The percentages of children in each age group who switched efficiently or inefficiently are shown in Figure 5.4.

Figure 5-4: Task switch score (% of children who select inefficient and efficient switch strategies)

Results in Figure 5.4 indicate developmental differences in task switching: just over 20% of 6-year olds switched between tasks efficiently compared to 50% of 8-year olds and over 80% of 10-year olds. Chi squared analysis indicates that all age groups are significantly different from one another. 6-year olds
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switched less efficiently than 8-year olds \( [X^2 = 47.22; \text{df} = 1; p < .01] \) and 10-year olds \( [X^2 = 25.56; \text{df} = 1; p < .001] \), and 8-year olds switched less efficiently than 10-year-olds \( [X^2 = 6.63; \text{df} = 1; p = .01] \). Therefore, results on this relatively direct measure of prospective memory support developmental differences across the 6 to 10-year age range.

**b) Strategic multitask performance**

The strategic performance score measures how well children apply the rules of the multitask paradigm to earn points. Age group scores for strategic performance are detailed in Table 5.10. One way analysis of variance indicated a significant main effect of age group on strategic performance score \( [F (2, 105) = 12.91, p < .001] \). Follow up Tukey HSD tests revealed significant differences between 6 and 8-year olds \( (p < .05) \) and 6 and 10-year olds \( (p < .001) \), but not between the 8 and 10-year olds \( (p > .05) \). This result indicates that 6-year old children are less able to use the rules governing the multitask paradigm to score points, although again this should be interpreted with caution given the reduced rule learning scores of this 6-year old group.

**Table 5-10: Multitask performance variables**

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Strategic Performance (score out of 18)</th>
<th>Penalty Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Errors N children</td>
</tr>
<tr>
<td>6-years (38)</td>
<td>9.81 (3.81)</td>
<td>9</td>
</tr>
<tr>
<td>8-years (35)</td>
<td>12.34 (3.80)</td>
<td>3</td>
</tr>
<tr>
<td>10-years (35)</td>
<td>14.14 (3.42)</td>
<td>3</td>
</tr>
</tbody>
</table>

**c) Penalty multitask performance**

We had anticipated that the older children would not make performance errors or break the ‘one-by-one’ rule as much as younger children. The numbers of children in each group who made errors or broke the rule are detailed in Table 5.10. In fact very few children made performance errors, although more 6-year olds did than 8 or 10-year olds. In addition, around 30% of children in each group broke
the 'one-by-one' rule; therefore predicted age group differences in rule breaking behaviour were also not observed.

[5] Recount

The recount score measures the child's ability to recall what they achieved during performance. Age group differences on recount scores were expected and group means are presented in Table 5.11. Analysis of variance indicated a main effect of group: $F(2, 105) = 5.15, p < .01$. Follow up Tukey HSD tests indicated that the main group difference was between the 6-year olds and the 10-year olds ($p < .01$) with all other group comparisons failing to reach significance. As group differences are between 6-year olds and 10-year olds, these results ought to be interpreted with caution.

Table 5-11: Recount scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Recount (score out of 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>6-years (38)</td>
<td>6.71 (2.35)</td>
</tr>
<tr>
<td>8-years (35)</td>
<td>7.54 (2.10)</td>
</tr>
<tr>
<td>10-years (35)</td>
<td>8.23 (1.52)</td>
</tr>
</tbody>
</table>
5.5 Discussion

The aim of this study was to investigate the development of children's ability to organise future behaviour. We used a multitask paradigm to assess future organisation skills in children. Multitasking tests have been used to elicit future-oriented behaviour in adults and this research has indicated that a range of cognitive processes underpin this ability (Burgess et al., 2000; Kliegel et al., 2000, 2002; Shallice & Burgess, 1991; Wilson et al., 1998). Our children's multitask paradigm enables evaluation of many of these underlying cognitive processes, and thereby extends existing investigations of multitasking in children (Emslie et al., 2003; Martin & Kliegel, 2003). We identified developmental differences in multitasking in children aged 6 to 10-years indicating that the ability to organise future behaviour develops in childhood. Furthermore, our results inform on the development of the various cognitive processes underlying the organisation of future behaviour in children.

Contrary to expectations, age group differences in retrospective memory performance were observed: 6-year old children were significantly less able to learn and retain the rules governing multitask performance than 8 and 10-year old children who learned them well. This result was unexpected as the task design and administration were aimed at minimising retrospective memory demands. The findings have implications for age group comparisons on other multitask variables as it is possible that 6-year old children were less knowledgeable about the purpose of 'the game' than older children. This difference in rule learning and memory represents a key limitation of this study, which we will address in our next study (Chapter 6) when we explicitly train children to learn the rules of the paradigm prior to performance. In the remainder of this discussion we interpret developmental differences between 6-year olds and older children bearing this limitation in mind.

The results support our hypothesis that children's ability to plan ahead in complex situations develops between 6 and 10-years of age. Group differences in planning scores were found between all age groups. Our scoring system enabled further analyses of these differences. Six and 8-year old children formed less complex plans than 10-year olds: 60% of 6-year olds and 50% of 8-year olds had to be prompted by the researcher to form a plan that included all three tasks. Ten-year old children also formed significantly more strategic plans than both groups of younger children as over 60% of 10-year
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olds explicated intentions to 'do yellow things' or to 'fill things up.' Although group comparisons involving the 6-year old children should be interpreted with caution, our results are consistent with other studies which support significant developments in planning skills in childhood between 6 and 12-years of age (e.g., Anderson, 1998; Levin et al., 1991, Welsh et al., 1991). Anderson (1998) reports that a particular period of development occurs between 8 and 9 years of age, this fits our pattern of results as it explains the differences observed between 6 to 8-year old children and 10-year old children.

Once children have formed a plan how likely are they to implement it? Older children not only plan better than younger children, but they also implement their plans more successfully. Group differences in plan following scores were calculated (co-varying for group differences in planning). Results indicated that whilst 8 and 10-year old children were able to implement the plans they had made, 6-year old children were significantly less able to follow through an intended plan of action. There are two explanations as to why 6-year old children were less able to implement their plans. The first is that they may not have had a clear idea of what they were actually planning to do. Six-year old children learned the rules of the paradigm less well than older children, so it is possible that they formed a plan without being entirely sure of what was required of them. It is more difficult to follow a poor plan than it is to follow a good plan (Burgess & Shallice, 1997; Kliegel et al., 2000; Mantyla, 1996). The second possibility is that 6-year old children may have had a clear idea of what they wanted to do, but lacked the ability to do it. Research with pre-school children indicates that there is a point in the development of planning skills when children are able to plan an action before they are able to control their behaviour sufficiently well to perform this action. This tension centres around two dynamic systems, a 'knowing' system and a 'doing' system, which are related to one another via inhibitory control mechanisms (Thelen & Smith, 1994). It is possible that 6-year olds experience a similar tension in our complex planning situation as they are unable to implement their intended plan. Klahr and colleagues (1993) studied planning independently of plan enactment by asking children to plan solutions on a Tower task without performing them. This manipulation benefited 6-year olds plans but not 8-year olds, indicating that a tension between planning and plan enactment is relevant for children of this age. Finally, a similar distinction has been reported in adult patients with frontal lobe damage who retained the ability to form a good plan of how to perform a multitask test but subsequently failed to implement this plan (Shallice and Burgess, 1991). We propose to investigate why 6-year old children are less
able to implement their plans in our next study (Chapter 6), in which we will train children to learn the rules of the paradigm. When 6-year olds have equivalent knowledge of task requirements to older children, how will this impact on their planning and plan following scores?

We found significant developmental differences between all age groups on the composite multitask performance variable, indicating that children’s ability to organise future behaviour develops between 6 and 10-years of age. Our novel paradigm and scoring system enabled us to investigate the factors underlying these developmental differences in multitask performance. We investigated task switching, strategic rule use and rule breaking/ error making.

Other children’s multitask paradigms elicit switching between tasks by having a greater number of tasks to perform (between 4 and 6) and a rule constraining the order in which these tasks can be performed. Strong developmental trends in the number of tasks attempted have been reported (Emslie, 2004; Martin & Kliegel, 2003). Task switching in the Battersea Multitask Paradigm is encouraged in a different way and, although only 60% of 6-year olds attempted to perform all three tasks, the majority of 8 and 10-year olds were able to do so. Task switching in our multitask paradigm is scored as inefficient or efficient according to how well participants move fluently between three interleaved tasks. Significant differences in task switching were found between all three age groups; confirming our hypothesis that as children grow older they become more efficient at switching between multiple tasks. Only 20% of 6-year olds switched efficiently, 8-year olds were just as likely to switch inefficiently as they were to switch efficiently, whilst over 80% of 10-year olds switched efficiently between tasks. Self-initiated task switching is a measure of prospective memory as remembering to switch between tasks relies upon the activation of a previously generated intention to switch. Our data provides evidence that children’s ability to implement multiple delayed intentions in complex situations develops between 6 and 10-years of age. This finding is consistent with developments in prospective memory skills across this age range (Brandimonte & Passolunghi, 1994; Kerns, 2000; Martin & Kliegel, 2003; Meacham & Colombo, 1980). Children find it easier to switch between tasks when performance on the ongoing task does not have to be interrupted (Kvavilashvili et al., 2001), reflecting the involvement of inhibitory control in prospective memory (Kliegel et al., 2002). In our multitask paradigm the most opportune time to switch to another task is after a cluster of items has been filled. We
observed that children in all age groups tended to switch after filling a cluster rather than during filling one. However, younger children often selected large clusters which take time to fill, or switched to another cluster in the same task rather than move to a small cluster in a different task: this contributed to their poor task switching. Hence, it is possible that younger children failed to switch between tasks as they failed to strategically apply the rules of the paradigm.

We predicted developmental differences in children’s ability to strategically use the rules of the multitask paradigm to earn points (strategic performance score), and this prediction was supported by our results. Although the only significant group differences were between the 6-year olds and the older children, and should therefore be interpreted with caution, strategic rule use continued to improve from 8 to 10 years of age. A similar pattern of development has been found in children’s ability to use strategies to solve complex planning problems (Anderson et al., 1996; Krikorian et al., 1994) and to facilitate prospective remembering (Kerns, 2000; Meacham & Colombo, 1980; Meacham & Dumitr, 1976). Six-year old children did not often use the rules of the paradigm strategically, they frequently failed to select more yellow items or smaller clusters of items that are faster to fill up. To some extent 8-year old children also failed to use the rules strategically. We considered how much this was because younger children did not understand the concepts of ‘yellow more than blue’ or ‘small is faster to fill,’ or if it was because they could understand these rules but found it difficult to apply them across multiple tasks. We will investigate this question in a subsequent study (Chapter 7), in which we ask children to apply these rules to individual rather than multiple tasks.

Frequent rule breaking is one of the hallmarks of multitasking performance in adult patients with frontal lobe damage (Shallice & Burgess, 1991). We designed our multitask paradigm to make rule breaking attractive to children too, so that we could investigate age group differences in rule breaking behaviour. We hypothesised that as children develop increasing inhibitory control over their behaviour, rule breaking would decrease accordingly. In fact, the temptation to break the ‘one-by-one’ rule was as strong for older children as it was for younger children as almost 30% of children in each group broke this rule. Performance errors are made when a child places an item incorrectly, for example placing a yellow item in a blue cluster. We hypothesised that uncorrected performance errors represent a failure of on-line performance monitoring and that the ability to monitor ongoing performance might be better
developed in older children. Although more 6-year old children made uncorrected performance errors than 8 or 10-year old children, so few errors were made that this result is difficult to interpret.

Performance monitoring is also assessed post performance when children are asked to recount what they did when they performed the task. The recount measure denotes the fact that prospective remembering is a dynamic activity, and that to achieve future goals successfully progress towards these goals must be evaluated in an ongoing fashion. This progress monitoring is accomplished by a system that keeps track of both what has been achieved (to prevent an action being needlessly performed again) and what remains to be done. Generally this system works well, however under conditions where processing resources are scarce, it can break down leading to everyday slips of action such as forgetting whether you locked the front door or paying a bill twice (Norman & Shallice, 1986). Age group differences in recount were predicted on the basis that children's ability to monitor and update performance of multiple actions will develop across the 6 to 10-year period, possibly as children access greater processing resources (Case, 1995; Gathercole et al., 2004). Age group differences in recount scores were found, however the only significant difference was between 6-year olds and 10-year olds. As comparisons involving 6-year olds ought to be interpreted with caution our results are less solid with respect to our hypothesis about the development of performance monitoring. However, an alternative explanation of our results ought to be considered before we discard our hypothesis; the scoring system we developed to score the recount variable may be too simple, as both 8 and 10-year olds score rather well on this measure. The recount score is less complex than other scores in our multitask paradigm, it is scored by assessing whether the child recalls how many of the three tasks they performed and the order in which they performed them. By contrast, the recount measure in the adult Greenwich Multitask Test is a more complex score in which participants' responses to a number of questions were scored (Burgess et al., 2000). In retrospect, our recount measure may prove to be too simple with ceiling effects likely to be found in participants aged 10-years and above. In future, it may prove useful to re-design this measure scoring answers to specific questions.
5.6 Summary of limitations and recommendations for future studies

Contrary to expectations, we found developmental differences in children's ability to learn and retain the rules of the paradigm. As 6-year old children did not have the same foundation from which to plan and perform the paradigm, it was difficult to interpret their scores on other variables relative to older children who learned and retained the rules of the paradigm well. We plan to address this limitation in our next study (Chapter 6) by training 6 and 8-year old children to learn the rules of the paradigm before they proceed to the planning and performance stages. We are encouraged by the consistency observed between children's rule learning and rule memory scores in the present study, as this implies that children retain the information that they learn.

We had hoped that by employing a more sophisticated method of scoring, our multitask would prove sensitive to potential developmental change and avoid ceiling effects. In general, the children in all age groups were able to multitask and most of the scoring systems we have developed were sensitive to developmental differences. It is possible that the recount scoring system is too simple, and this limitation should be considered in any future revisions of the Battersea Multitask Paradigm. One way to achieve this would be to devise specific questions to probe the extent of children's knowledge of what they have done.

Another interesting question that was raised concerns the development of children's strategic rule use. Young children were less consistent in their ability to use the rules to govern their multitask performance, and we were not sure whether this was because they could not apply these rules or whether it was because they could not apply them in a multitask situation. We shall investigate this in a single task study in which we ask children to apply these rules to single tasks, thus removing the complexity of a multitask situation (Chapter 7).

Finally, although our task was simple enough for young children to attempt, even 10-year olds did not score at ceiling on most variables. This indicates that we could investigate the performance of older children and possibly adults using the Battersea Multitask Paradigm. In Chapter 8 we administer our multitask paradigm to 14-year old adolescents and young adults.
5.7 Chapter summary

In this study we have demonstrated that children’s ability to organise future behaviour develops between 6 and 10-years of age. To the best of our knowledge, this is the first time that the cognitive processes underlying the organisation of future behaviour in children have been studied as part of a complete future-oriented episode. We have identified developmental differences in many of these underlying cognitive processes, specifically in children’s ability to plan multiple prospective actions, to implement this plan, and to co-ordinate and monitor performance across multiple tasks; reflecting developments in prospective memory and executive processes.
Chapter 6 - Multitask training study

6

Multitask training study

A key limitation of the multitask study reported in Chapter 5 was that rule learning was not adequately controlled for. Contrary to expectations, 6-year olds did not learn the rules governing multitask performance as well as older children. Therefore the 6-year olds knowledge of ‘how to play’ the multitask game was likely to have been qualitatively different from that of 8 or 10-year old children. This result compromised age group comparisons between 6-year olds and older children on other variables generated by the multitask paradigm. In order to address this issue, the 6 and 8-year old children in the present study were trained to learn the rules governing multitask performance to a pre-set criterion.

6.1 Introduction

In the multitask study reported in Chapter 5 (hereafter referred to as the “previous multitask study”), the assumption that children of all ages would be equally able to learn and retain four simple rules proved to be incorrect. This assumption was based upon the design, administration and piloting of the multitask paradigm. We developed four simple rules to govern task performance, and piloting indicated that children were able to use these rules to perform the paradigm. Moreover, during task administration the rules are repeated to the child a number of times; when they are taught how to play
the games and when they are explicitly told the rules. In the sections below we review adult and child multitask paradigms to evaluate how they ensure that participants have knowledge of the rules.

6.1.1 Rule learning in adult multitasking paradigms

In most adult multitasking studies, participants' knowledge of the rules is not quantitatively reported. However, examination of the task administration methods reveals that adults typically do not begin performing the multitask until they are able to repeat all the rules. For example, Kliegel and colleagues (2000) reported that their adult participants did not proceed to perform the HEXE multitask test until they were able to recall the rules perfectly. In another study using the HEXE paradigm, the same research team expanded upon this methodological information, saying that adults were tested for their recall of the rules, that any errors or omissions were corrected, and that the task was not performed until participants were 'aware' of the rules (Kliegel et al., 2002). Unfortunately, in both studies, data concerning the number of repetitions necessary to achieve perfect recall was not reported. These authors are not alone in this lack of specification. The administration procedure of the Six Elements Test (SET) and the Multiple Errands Test (MET) was similarly qualitatively described (Shallice & Burgess, 1991). In these tasks, when participants were unable to recall a rule the entire list of rules was re-read, following which recall was tested again. This process was repeated until all the rules were recited correctly, however the number of repetitions required by participants (patients and controls) was not reported. The authors were aware that retrospective memory for the rules governing performance could play a role in 'patient versus control' group differences, and addressed this issue in their discussion. Specifically, none of the three patients exhibited retrospective memory difficulties on the SET and one patient was not impaired on other tests of retrospective memory conducted (for example digit span, words and faces recognition memory, Rey Complex Figure and story recall). Another patient performed well on verbal tests of retrospective memory (story recall, word recognition memory), but was impaired on tests of non-verbal memory (Rey Complex Figure, face recognition memory). A third patient also exhibited retrospective memory difficulties, but only on unstructured tests (Rey Complex Figure and paired associate learning); leading the authors to conclude that her retrospective memory impairment was secondary to her frontal/ organisational difficulties (Shallice & Burgess, 1991). All three patients performed well on the digit span task, a test of memory span and working memory.
In the Greenwich multitask paradigm, on which our Battersea Multitask Paradigm is modelled, rule learning was explicitly scored and these scores were reported (Burgess et al., 2000). Adult participants' free-recall of the rules was tested, and their cued rule learning was tested by a series of questions about the rules of the Greenwich paradigm. If participants answered any cued questions incorrectly, the list of rules was repeated once more, following which participants are asked the cued questions once again (Burgess et al., 2000). However, this 'rule training' did not eliminate significant group differences in rule learning between patients and controls.

From the studies reviewed above, it is clear that rule learning is often part of the multitask administration procedure in adult studies and should have been included in our previous multitask study for children, despite the simplicity of our rules. Having said this, although studies mention rule learning in the methods section, data on this aspect of multitask performance are reported infrequently. Perhaps rule learning is not really an important issue for adult participants? One might assume that in a large enough sample, adults would have a broadly equal capacity to learn and retain rules; hence the lack of data on rule learning may simply reflect this. In contrast, in developmental studies, age related differences in rule learning and retrospective memory could have a profound effect on prospectively remembered intentions.

6.1.2 Rule learning in children's multitasking studies

Is rule learning accounted for in children's multitask studies? Martin & Kliegel (2003) administered their computerised HEXE multitask paradigm to children aged 6 to 11-years. Although the authors didn't report data regarding how well children learned or remembered the rules in the published study, they did test rule knowledge at the instruction phase and at the end of the procedure and found no age-group differences (Kliegel, personal communication). Children who did not have perfect recall of the two rules of the paradigm were told the rules again until they had learned them. Unfortunately the number of repetitions required by these children was not recorded, therefore it remains possible that there were age differences in the number of repetitions children required to learn the rules.

In the Six Parts Test, Emslie and colleagues (2003) repeated the rules twice whilst teaching children how to play the game, following which the child's knowledge of the two rules was tested. If the child
made any errors whilst summarising the rules, the instructions were repeated and the child asked to summarise the rules once more. Regardless of the accuracy of this summary, the child proceeded to perform the test. An instruction sheet containing information about the rules and how to play the tasks was left on the table in front of the child during the test. The child’s knowledge of the rules was not scored and their awareness of the demands of the test was not assessed post performance. In sum, each child had three opportunities to hear the rules of the test and two opportunities to summarise them, after which testing proceeded regardless of how well the child had learned these rules (although they could refer to the instruction sheet when in doubt). The majority of children assessed were able to summarise the demands of the test, although children younger than 8-years of age occasionally found this challenging (Emslie, personal communication).

In the Children’s Six Elements Test (C-SET, Siklos & Kerns, 2004), the three rules of the test were explained only once, after which children’s memory and understanding of them was tested via a series of questions. Children began the task “once it was established that they fully understood the rules…” (Siklos & Kerns, 2004, page 347). The same questions were repeated after children had performed the task to test recall. The authors reported than none of the children had any problems answering these questions either prior to or post performance, although no further information about the questions or children’s responses to them was reported.

Finally, retrospective memory differences in pre-school children may influence performance on prospective memory tasks (Guajardo & Best, 2000). Young children were asked to remember to perform future actions, such as giving the researcher a card before nap time. If a child failed to act upon presentation of the appropriate cue (e.g., the researcher) they were prompted to do so; 3-year old children required more prompts than 5-year old children. Retrospective memory was tested at the end of the session using open-ended questions to assess whether children who had failed to act remembered the intended action at all. There were significant age group differences in retrospective memory for prospective intentions: over 80% of 5-year-olds responded to the questions correctly compared to only 50% of 3-year-olds. The authors themselves stated that “…this finding demonstrates a greater comprehension of the task by the older children” and concluded that the retrospective aspect of the task may have been difficult for children (Guajardo & Best, 2000, page 90). This study supports
the possibility that age differences in retrospective memory impact upon prospective memory performance in children.

In sum, children's multitask paradigms also emphasise the importance of learning the rules prior to performance. However, details of how children of different ages learn the rules are not often recorded or reported, hence it is not always clear how this rule learning is achieved. In the HEXE and C-SET, children do not proceed to perform the test until they have learned the rules. In the Six Parts Test, children perform the task even if they have not been able to summarise the rules, although they can refer to an information sheet at any time. All these multitask tests recognise the importance of understanding the test demands prior to performance. Controlling this understanding is essential for cross-age comparisons. If children don’t hold (retrospectively) the same knowledge of the intended action, any age-related differences in prospective memory performance will be compromised by this qualitative difference in children’s awareness of what it is they are supposed to remember to do.

6.1.3 Rule training

Having identified the need to train young children to learn the rules of our paradigm we needed to develop a rule training method. Three multitask studies elaborate on their rule training methods. Kliegel and colleagues (2002) emphasised forgotten rules, correcting errors or omissions made by their adult participants. In the Six Parts Test (Emslie et al., 2003) and the Six Elements Test (Shallice & Burgess, 1991), the focus of administration was not specifically aimed at forgotten information. If participants omitted rules or recalled them incorrectly, all the rules were repeated again. The rule training method we have developed is a hybrid of these two methods.

The training method used in this study was twofold; involving testing rule knowledge and focusing on forgotten as well as remembered rules. A typical cumulative list-learning procedure involves reading aloud a list of words and testing free-recall (words can be recalled in any order). Once the participant has recalled as many words as possible the list is simply read again, and following this repetition the participant is asked to free-recall as many words as possible. This process is repeated until a predetermined number of repetitions has been reached. This method may be most suited for a memory test, however in the present study, the aim was to help the children to learn and retain the rules of the
game. Therefore, once the child had free-recalled the rules, the researcher congratulated the child for the rules already learned (repeating them again, thereby consolidating memory for them) and in addition, highlighted the rules that the child had forgotten by repeating these too. In this way both remembered and forgotten rules were focused on, a process aimed at helping children to learn the information more easily. After each repetition, the children's free-recall of the rules was tested up to a maximum of three repetitions. Children who failed to learn the rules after three repetitions performed the paradigm but their data was excluded from further analyses.

We trained new groups of 6 and 8-year old children to learn the rules and explored age group differences in scores on key multitask variables. Our hypotheses are summarised below.
6.2 Aims and hypotheses

The aim of this study is to train 6 and 8-year old children to learn all the rules of the paradigm before they proceed with the task. The results from our previous multitask study indicated differences between 6 and 8-year old children on some key multitask variables. The question of interest is - what will happen to these group differences once rule learning has been properly controlled? We hypothesise that the majority of age group differences between 6 and 8-year old children in will remain. Our hypotheses are summarised below.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group Differences?</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule Learn &amp; Memory</td>
<td>No</td>
<td>Rule training will preclude group differences on rule learning scores, however we anticipate that 6-year olds will require more repetitions to learn the rules than 8-year olds. Given the consistency between rule learning and rule memory scores in the previous multitask study we do not expect differences in rule memory.</td>
</tr>
<tr>
<td>Plan</td>
<td>No</td>
<td>In the previous multitask study 6 and 8-year olds did not differ from one another in their ability to plan how to perform the task. As 8-year olds were able to learn and retain the rules of the paradigm, but planned at a level similar to 6-year olds, we expect no group differences in this study.</td>
</tr>
<tr>
<td>Plan Follow</td>
<td>Yes</td>
<td>6 and 8-year old children in the previous multitask study formed plans of a similar quality but did differ significantly in their ability to implement these plans. We expect this finding to remain in the present study.</td>
</tr>
<tr>
<td>Multitask Performance</td>
<td>Yes</td>
<td>In the previous multitask study 6-year olds were significantly less effective 'multitaskers' than 8-year olds. In keeping with the hypothesis that children's ability to organise future behaviour develops, we anticipate that this group difference will remain.</td>
</tr>
<tr>
<td>Task Switching</td>
<td>Yes</td>
<td>Group differences in task switching are expected. In the previous study the majority of 6-year olds were inefficient at switching between tasks, which we hypothesise is due to less well developed prospective memory skills.</td>
</tr>
<tr>
<td>Strategic Performance</td>
<td>Yes</td>
<td>Although it is possible that knowing the rules better will influence a child's ability to apply them strategically, there is a body of evidence which supports the development of executive strategy use across middle childhood and we anticipate significant group differences on this measure.</td>
</tr>
<tr>
<td>Rule Breaking</td>
<td>No</td>
<td>In our previous multitask study 1/3 of children broke the rules and no age group differences in rule breaking were observed. We are interested to see if this result will be replicated in the present study.</td>
</tr>
<tr>
<td>Performance Errors</td>
<td>No</td>
<td>Very few children made performance errors in our previous multitask study and the same result is anticipated in the present study.</td>
</tr>
<tr>
<td>Recount</td>
<td>No</td>
<td>6 and 8-year old children did recount significantly differently from one another in the previous multitask study and we did not anticipate group differences.</td>
</tr>
</tbody>
</table>
6.3 Method

6.3.1 Study design
This study is a cross-sectional, between-groups design. Two groups of children were recruited to the study, a group of 6-year old children and a group of 8-year old children.

6.3.2 Ethical considerations
Ethics approval for this study was covered by ethical approval granted for the previous multitask study. As previously, written parental consent was obtained for each child who participated, plus additional permission to video the test session. Parents were given opportunities to ask questions about the study; the researcher was available in school at a specific date and time, and the researcher’s contact details were included in all study information. Verbal assent was sought from each participating child, as was permission to video the session. No child whose parents had consented objected to participating in the study. Children received a certificate and a small reward for participating in the study (a Great Ormond Street Pencil). School classes received book tokens (typically £15) as a way of thanking them for their help.

6.3.3 Participants

Recruitment
Children, different from those in the previous multitask study, were recruited from a mainstream primary school which had participated in the previous study. The school performed at the national average on standardised tests of key educational subjects. The Head Teacher was approached via letter and asked if he would permit children to participate in the study, this letter was followed up by a phone call and an appointment to discuss the study further. Once the Head Teacher’s permission had been obtained, the researcher met class teachers to explain the study and give them recruitment letters and consent forms. Class teachers distributed letters to the parents of all children in each participating class. In the letter parents were provided with information about the study and given the opportunity to
ask questions. An enclosed consent form was to be returned to the class teacher. After forms had been returned convenient testing times were arranged.

**Response rates**

One school participated in the study and children were recruited from two classes, a 6-year old class and an 8-year old class. There were approximately thirty children in each class. Of the sixty letters sent home to parents of 6-year old children, 25 were returned of which 24 granted consent. Of the sixty letters sent home to parents of 8-year old children, 24 were returned of which 21 granted consent. All children whose parents consented were assessed.

6.3.4 Procedure

**Test environment**

Test sessions were conducted in a quiet room of the school. The researcher collected and returned each child to and from class. During the session the child was seated at a table opposite the researcher. As the procedure was videotaped for analysis, a camcorder fixed on a tripod was placed behind the researcher (to one side) and focused on the child’s head and hands with a view of all three tasks. The three tasks used in the paradigm were laid out horizontally on the table between the child and the researcher. The arrangement of the 3 tasks on the table was counterbalanced between children, with 6 possible arrangements of the 3 tasks.

**Test administration**

The total testing session took 20 minutes. At the end of the session children were thanked, given a certificate and small prize, and accompanied back to their classroom.

For the most part, the administration of the multitask paradigm remained unchanged, following the set procedure outlined previously in Chapter 4. The only changes to the procedure are the rule training aspect of the study, which is detailed below and in Appendix 3. The entire procedure was videotaped for analysis. In addition to video scoring, the researcher filled in a score sheet during task administration. As before, children performed three practice tasks and once the researcher was satisfied that they understood how to ‘play the games’ the child was guided through the following steps.
generating six key variables (see Figure 6.1). Children were trained to learn the rules of the paradigm and were given up to three repetitions of these rules. Changes to the rule learning stage are discussed below, all other scores are derived as before. Following rule training, children proceed through the same administration stages as before: plan, plan follow, perform, recount and remember.

_Figure 6-1: Multitask rule training administration procedure and key variables_

**Variable generated** | **Stage of task administration**
--- | ---
Rule Learn/Rule Train | Free-recall of the 4 rules of the paradigm
 | Up to 3 x repetitions
 | Cued-recall of the 4 rules of the paradigm (9 questions)
Plan | Ask children how they intend to ‘play the game’
Plan Follow | What children did in comparison to what they planned to do?
Perform | How children score overall when performing the task
Recount | Children’s ability to describe what they have done
Remember | Retrospective free and cued-recall of the 4 rules

**Rule training administration and scoring**

The training method used in this study involved testing rule knowledge and focusing on forgotten as well as remembered rules. The child’s free-recall of the rules was tested up to a maximum of three times by asking the question - ‘now, can you tell me the four rules of the game?’ If a child omitted a rule during free-recall, the researcher not only repeated remembered rules, but also highlighted any
rules which had been forgotten. For example the researcher might say – ‘good, you remembered that ‘yellow things get more points than blue’ and that ‘filling things up gives you bonus points.’ But you forgot two rules – ‘you must try all three games’ and ‘you can only pick things up one-by-one.’ Now, listen carefully and I’ll read all four rules again....’ In this way, the forgotten rules as well as the remembered rules were reinforced. It was hoped that this method would facilitate children’s ability to learn and retain the rules of the game. We set a maximum of three repetitions, as it was felt that children who required more than three repetitions of the rules, over and above being taught how to ‘play the games,’ were not meaningfully able to learn the rules. Once the child had recalled all four rules, cued rule learning was assessed by asking 9 questions about the paradigm (as outlined previously in Chapter 4).

Scores for free-recall and cued-recall are derived in much the same way as in the previous multitask study, with one exception; in the training study free-recall is administered up to a maximum of three times. A participant who correctly recalls all 4 rules on the first occasion is not asked to free-recall the rules again, but moves on directly to answer the cued-recall questions. A participant who fails to mention all 4 rules on the first free-recall opportunity is given up to two further opportunities to do so. If failure persists, the participant’s data are not included in the analyses. Only participants who meet criterion (all 4 rules learned after a maximum of 3 free-recall repetitions) are included in the study.

In this training study the free-recall rule learning score is taken as the participants score on their final cued-recall repetition (whether this is the 1st, 2nd or 3rd); therefore free-recall is still scored out of a maximum of 8 points. The number of repetitions required for each participant is also recorded (minimum 1, maximum 3). Once a child has met criterion for free-recall rule learning, cued rule learning is assessed as in the previous multitask study. The child’s knowledge of the rules and demands of the game is assessed via a series of nine questions and cued-recall is scored out of a maximum of 10 points. As previously, free and cued-recall scores are summed to give the composite ‘rule learning’ variable with a maximum of 18 points.
6.4 Results

6.4.1 Exploration of the data

Sample Characteristics

39 children participated in this study: a 6-year old group (N = 18), and an 8-year old group (N = 21). Distribution of ethnic diversity was also equal with 80% of children in each group being Caucasian: 6-year olds (15 Caucasian, 1 Asian, 1 Chinese and 1 Mixed Race), 8-year olds (17 Caucasian and 4 Afro-Caribbean). Details of the sample are in Table 6.1.

Table 6-1: Sample Characteristics

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Age (years, months)</th>
<th>SD (months)</th>
<th>Range (months)</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-years (18)</td>
<td>6y 1m</td>
<td>3.81</td>
<td>66 - 78</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>8-years (21)</td>
<td>7y 11m</td>
<td>3.64</td>
<td>90 - 101</td>
<td>13</td>
<td>8</td>
</tr>
</tbody>
</table>

Cases excluded from analyses

A total of 45 children were assessed. Six children were excluded as they failed to learn all four rules after three attempts to do so. These children were all 6-years old (4 male, 2 female, mean age = 6 years, 0 months). They were allowed to 'play' the game under timed conditions and received a certificate and a prize like other participants, however they were excluded from subsequent analyses.

Parametric or non-parametric analyses?

In the previous multitask study an examination of the standard deviations of key variables revealed greater variance in the performance of younger children than older children; thereby violating the assumption of homogeneity of variance upon which parametric statistical analyses rely. A similar investigation in the present study revealed that group comparisons on some variables failed Levene’s test for homogeneity of variance. Non-parametric Mann Whitney U tests, which do not presume homogeneity of variance, were calculated for all group comparisons where equal variance could not be
assumed. In all comparisons except one, the results were no different to those obtained by their parametric equivalents. The only exception was the 'recount' variable which is discussed below. Otherwise, for the sake of consistency and parsimony all analyses reported will be parametric analyses.

6.4.2 Group comparisons on multitask variables

Figure 6.2 displays age-group performances on the six key variables generated by multitasking (in percentages, as scores are summed out of different totals).

Figure 6-2: Group performance on the six key multitask variables (in %)

Examination of the variables in Figure 6.2 indicates group differences in some but not all aspects of multitasking. These results are explored below.
Chapter 6 - Multitask training study

[1] Rule Learning and Rule Memory

In this study we controlled rule learning and only children who were able to learn all four rules were included in the analyses. Rule learning and memory scores are detailed in Table 6.2, along with the mean number of repetitions of the rules required by each age group. The rule learning score was calculated as the child’s free-recall rule learning score on the first occasion on which they learned all four rules (this might be on the 1st, 2nd or 3rd repetition), plus their cued-recall score.

Table 6-2: Rule Learning and Rule Memory Scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Rule Learning (score out of 18)</th>
<th>Rule Memory (score out of 18)</th>
<th>Mean Number of Repetitions (1-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-years (18)</td>
<td>16.44 (1.14)</td>
<td>15.06 (1.62)</td>
<td>2.21 (0.71)</td>
</tr>
<tr>
<td>8-years (21)</td>
<td>16.86 (0.80)</td>
<td>16.20 (1.63)</td>
<td>1.60 (0.51)</td>
</tr>
</tbody>
</table>

Given that inclusion in the study relied upon meeting pre-determined criteria, no significant group differences in rule learning scores were observed \[F (1, 37) = 1.74, \text{NS.} \]. This indicates that children of both ages were able to learn the rules of the paradigm. We had predicted that the number of repetitions required by children in each age group to learn all four rules would be different, with younger children requiring significantly more repetitions than older children. This difference was confirmed \[F (1, 37) = 9.31, p< .01 \]; indicating that whilst 6-year old children were able to learn the rules of the game, they required more coaching to achieve this end.

This result may impact upon the unexpected finding of significant age-group differences in post-performance retention of the rules, as measured by the rule memory variable \[F (1, 37) = 4.70, p< .05 \]. In the previous multitask study, there was remarkable consistency between rules learned and rules retained and a similar level of consistency had been expected in the present study. Rule memory is also a composite of free and cued-recall scores, and we investigated whether age group differences observed may be attributable to one or other of these scores. No significant group differences were found between 6 and 8-year olds free-recall rule memory, scored out of 8 points \[\text{mean 6-years} = 6.05, \text{SD}=1.40; \text{mean 8-years} = 6.86. \text{SD}=1.42: F (1,37) = 0.85, \text{NS.} \]. Nor were any age-group differences...
observed for cued-recall rule-memory, scored out of 10 points [mean 6-years = 9.00, SD=0.81; mean 8-years = 9.71, SD=1.60: F (1, 37) = 1.74, NS.]. These results indicate that the group difference in memory for the rules is only apparent after these scores are combined to form the composite rule memory variable, as neither form of assessing rule memory was in itself the major source of age group differences. In sum, it is possible that whilst younger children could be trained to learn the rules, their representation of them may remain somewhat less robust. This issue will be revisited in the discussion section below.

We compared the rule learning and rule memory scores of 6 and 8-year old children in the present training study to that of 6 and 8-year olds in our previous multitask study. The results indicate that rule training has had a positive effect on both learning and remembering the rules. 6-year olds in the training study learned over 90% of the rules, compared to 6-year olds in the first study who learned little over 60% of the rules. Even the performance of 8-year olds, who learned the rules fairly well in the first study, seems to have been improved upon by specific rule training; as their rule learning score rose from just below 90% in the first study to just above 90% in the training study. Likewise, rule memory improved for the 6-year olds between the previous multitask study in which just over 60% remembered the rules, and the present training study in which just over 80% remembered the rules. Rule memory scores of 8-year olds also improved from just over 80% of rules remembered in the previous multitask study, rising to just under 90% in the present training study.

[2] Planning

Age group differences on the planning variable of the multitask paradigm were not anticipated and were not found. Mean planning scores are detailed in Table 6.3, analysis of variance indicated that there were no significant group differences [F (1, 37) = 0.84, NS.]. This result was not surprising given the lack of differences between 6 and 8-year olds planning scores in the previous multitask study.
Table 6-3: Planning scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Planning (score out of 12)</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-years (18)</td>
<td></td>
<td>8.38 (3.47)</td>
</tr>
<tr>
<td>8-years (21)</td>
<td></td>
<td>8.90 (2.66)</td>
</tr>
</tbody>
</table>

Like the other key variables generated by the multitask paradigm, the planning score is a composite variable. Scores reflect both the complexity of the plan and the level of strategic intent contained in the plan. Were these non-significant group differences reflected in all aspects of planning, or did 6 and 8-year old children’s plans differ in complexity or strategic content?

Plan complexity is measured by the number of tasks that children plan to perform. Children whose plans did not at first include an intention to attempt all three tasks were encouraged to do so, and multitask performance did not begin until this had been achieved. The complexity of plans produced in the training study are detailed in Figure 6.3.

Figure 6-3: Complexity of plans (% of children who needed prompting)
The results illustrated in Figure 6.3 paint a very different picture to those of the previous study. Having been trained to learn the rules of the paradigm, the majority of 6 and 8-year old children are able to form plans that involve performing all three tasks without prompting. It appears that rule training has had a positive impact upon complex planning. Would this positive impact extend to strategic planning?

The strategic planning score is derived by awarding points when a child plans to use the rules of the paradigm to their advantage (i.e. to earn more performance points). This includes planning to prioritise yellow items and planning to fill items to earn more points. Scores are reported in Table 6.4, as the percentage and number of children in each group whose plan included any of these strategic elements.

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>% whose plan included any of these strategic elements (N)</th>
<th>Prioritise yellow</th>
<th>Fill clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-years (18)</td>
<td>44.4% (8)</td>
<td>55.5% (10)</td>
<td></td>
</tr>
<tr>
<td>8-years (21)</td>
<td>38.1% (8)</td>
<td>66.7% (14)</td>
<td></td>
</tr>
</tbody>
</table>

The results in Table 6.4 indicate that there were no significant group differences in the extent to which children planned to prioritise yellow items \( F (1, 37) = .03, \text{NS.} \), or to fill clusters of items \( F (1, 37) = .48, \text{NS.} \). These results replicate those of our previous multitask study, in which no significant differences between 6 and 8-year old children were observed for either measure of strategic planning. What is interesting is that once again rule training appears to have had a positive effect, this time on strategic planning. In the previous multitask study only 23% of 6 and 8-year olds planned to prioritise yellow items, in the present study this rose to around 40% of children. Likewise, in the previous multitask study approximately 30% of children planned to prioritise filling clusters of items, whilst in the present study 55-66% of children included this intention in their plan.

Overall, both 6 and 8-year old children's planning scores benefited from rule training. 6-year olds scored an average of 45% of available points when planning in the previous multitask study, compared
to an average of 70% of points in the present training study. Similarly 8-year olds achieved 50% of planning points in the previous multitask study and obtained a mean of 75% in the present study. The implications of this finding will be discussed further.

[3] Plan Follow

Group differences in plan following had not been anticipated in the present study on the basis that none were observed in the previous multitask study. Plan following scores are detailed in Table 6.5.

Table 6-5: Plan following scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Plan Follow (score out of 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>6-years (18)</td>
<td>6.05 (2.92)</td>
</tr>
<tr>
<td>8-years (21)</td>
<td>7.86 (2.13)</td>
</tr>
</tbody>
</table>

As anticipated, significant group differences in plan following were observed. Between groups analysis of variance indicated that 6 and 8-year old children scored significantly differently from one another on the plan following variable \[ F (1, 37) = 4.94, p< .05 \]. Recall that the plan following score is calculated as the original planning score minus any deviations from this plan. As a consequence of this scoring method, the plan following score is closely related to the planning score. Therefore, when we investigate group differences in plan following, planning scores should be accounted for. To achieve this, analysis of covariance (ANCOVA) was performed, co-varying for planning. Group differences in plan following remained significant after planning scores were co-varied \[ F (1,37) = 7.10, p< .01 \], estimated marginal means 6-years = 6.22, standard error = .41, 8-years = 7.71, SE = .38. Therefore, despite the fact that in the present study both age groups plan at an equivalent level, 8-year olds were significantly more able to follow through this plan than 6-year olds. This finding is in accord with the results of the previous multitask study, in which 6 and 8-year old children implemented their plans at different levels.
Chapter 6 – Multitask training study


Significant group differences in children's ability to perform the multitask paradigm were anticipated and found \( F (1, 37) = 6.52, p < .05 \), indicating developmental differences in the overall ability of 6 and 8-year old children to organise future behaviour. The means detailed in Table 6.6 indicate that 8-year old children outperformed 6-year old children. The multitask performance scores of 6 and 8-year old children in the training study are remarkably similar to the scores obtained by their peers in the previous multitask study. 6-year olds scored an average of 40% of performance points in both studies, and 8-year olds scored an average of 60% of points in both studies. Unlike other variables generated by multitasking, overall performance does not seem to have been facilitated by rule training.

### Table 6-6: Multitask Performance Scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Composite Multitask Performance (score out of 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>6-years (18)</td>
<td>8.61 (5.95)</td>
</tr>
<tr>
<td>8-years (21)</td>
<td>12.71 (3.90)</td>
</tr>
</tbody>
</table>

As multitask performance is a composite variable, we investigated whether the same pattern of age group differences would be observed for the scores contributing to this the composite score. Older children were expected to perform more tasks (out of a maximum of 3) than younger children and results supported this hypothesis: 61.1% of 6-year olds performed all three tasks compared to 90.5% of 8-year olds. Chi squared analysis confirmed that significantly fewer 6-year olds performed all three tasks than 8-year olds \( \chi^2 = 4.71; df = 1; p < .05 \). This result is also very similar to the results of the previous multitask study, in which 60% of 6-year olds and 83% of 8-year olds attempted all three tasks.

**(a) Task switch performance**

The number of times a child switched from one task to another is recorded and categorised as 'efficient' or 'inefficient.' The distribution of switch scores for children in both age groups is represented in Figure 6.4. The dotted lines represent the lower and upper limits of the 'efficient' switch strategy. Outside this area lie the 'inefficient' strategies. As discussed in previous chapters, the minimum number of switches considered to be 'efficient' is 3. In the present study the upper limit was set at a maximum of 11
switches. Only one child switched more than 11 times, this child switched quite randomly between tasks and failed to fill whole clusters prior to moving on to another task.

**Figure 6-4: Distribution of number of task switches – all age groups**

We predicted group differences in task switching. The percentages of children in each age group who switched efficiently or inefficiently are shown in Figure 6.5.

**Figure 6-5: Task switch strategy (% of children who adopted either switch strategy)**
Although the results in Figure 6.5 indicate that more 8-year olds adopted an efficient switching strategy than did 6-year olds, Chi squared analysis revealed that these differences were not significant between groups \( [X^2 = 1.21; \text{df} = 1; \text{NS.}] \). Just over 60% of 8-year-olds adopted an efficient switch strategy, whilst 6-year olds were just as likely to adopt either strategy. This result was unexpected, as in the previous multitask study 80% of 6-year olds failed to adopt an efficient switch strategy. In contrast, both 6 and 8-year old children in the present study resemble the 8-year old children in the previous multitask study, 55% of whom selected an efficient switch strategy. Rule training appears to have raised the task switching scores of the 6-year olds to an 8-year old level.

(b) Strategic multitask performance

Group differences on the strategic multitask performance score were anticipated, as 6-year old children in the previous multitask study were significantly poorer at strategically applying the rules of the paradigm than 8-year old children, and because executive/strategic skills develop from age 6-years onwards. Group scores for the strategic performance measure are detailed in Table 6.7. One way analysis of variance indicated a significant group difference \( [F (1, 37) = 8.10, p< .01] \). This result supports developmental differences in the extent to which children of different ages used the rules to their strategic advantage, with 6-year olds demonstrating less proficiency than 8-year olds. In addition, rule training did not have an impact on these strategic performance scores. In the present study 6-year olds obtained 53% of possible points compared to 54% of points in the previous multitask study. Similarly, 8-year olds obtained 71% of possible points compared to 68% in the previous multitask study. Hence, the groups scored at a remarkably similar level across both studies.

Table 6-7: age group performance on executive measures

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Strategic Performance (score out of 18)</th>
<th>Penalty Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Errors (N children)</td>
</tr>
<tr>
<td>6-years (18)</td>
<td>9.44 (4.50)</td>
<td>1</td>
</tr>
<tr>
<td>8-years (21)</td>
<td>12.95 (3.22)</td>
<td>3</td>
</tr>
</tbody>
</table>
(c) Penalty multitask performance

The results in Table 6.7 indicate that very few children made performance errors, this resembles the results of the previous multitask study. No group differences in error making emerged. In this training study almost 50% of children in each age group broke the one-by-one rule. This is a substantially higher proportion of children than in the previous multitask study, in which only 30% of children broke this rule. Despite this increase in rule breaking, no group differences were observed.

[5] Recount

In the previous multitask study we failed to find group differences between 6 and 8-year old children’s ability to recount what they had achieved during performance. On the basis of these results we had not expected to find group differences in the present training study. Mean recount scores are presented in Table 6.8. Whilst one way analysis of variance indicated a significant group difference for recount $[F (1, 37) = 5.15, p< .05]$, the variance on this measure was too great and homogeneity of variance could not be assumed ($\text{Levene Statistic (df 1, 37) = 9.79, p< .01}$). A follow up non-parametric Mann Whitney U test failed to elicit a significant group difference $[z = -1.83, \text{NS.}]$. Recount scores obtained for both groups closely resemble those obtained in the previous multitask study.

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Recount (score out of 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>6-years (18)</td>
<td>6.81 (2.36)</td>
</tr>
<tr>
<td>8-years (21)</td>
<td>8.14 (1.31)</td>
</tr>
</tbody>
</table>

[5] Additional Analyses

We were interested to observe that whilst planning scores improved in the training study, multitask performance scores remained the same as in the previous multitask study. To investigate how these variables interact in the training study we transformed the planning and composite multitask performance scores into $z$ scores. This places them on the same standard distribution and enables us
to compare them to one another. z scores are calculated as the individual’s score on the variable of interest, $X$, minus the population mean score, $\mu$ (of all participants in the sample, i.e. both groups), divided by the population standard deviation, $\sigma$ (of both groups). The formula for calculating a z score is summarised below:

$$z = \frac{X - \mu}{\sigma}$$

z scores for planning and performance are plotted in Figure 6.6. The pattern of scores indicates that although rule training raised the level of children’s planning, 6-year old children failed to implement their plans whilst 8-year olds out-performed their plans. This pattern of results will be considered further in the discussion.

Figure 6-6: z-scores for planning & performance in rule-trained 6 and 8-year olds
6.5 Discussion

The aim of this training study was to control differences in children's ability to learn the rules of the multitask paradigm. This is important because learning the rules of the paradigm enables children to understand the demands of the tasks before them, and provides a measure of retrospective memory for intentions. A significant relationship between retrospective memory for the intended action and prospective memory to implement this intention has been proposed in adults (Burgess & Shallice, 1997; Graff & Uttl, 2001; Kvavilashvili, 1998), as well as children (Guajardo & Best, 2000). If a child cannot remember what it is they are supposed to do, how will they remember to do it? We controlled group differences in 6 and 8-year old children's rule learning by training them to learn the rules prior to performance. A rule training method was employed which successfully raised 6 and 8-year old children to same level of rule learning, as was evidenced by the lack of significant differences between scores on this measure. In this way, we ensured that children's knowledge of the retrospective content for ‘to-be-remembered’ actions was as equal as possible prior to performing the task. Rule training influenced the scores of both age groups on other multitask variables, but had no impact on overall multitask performance. These results are discussed below.

Six and 8-year old children achieved equal rule learning scores, indicating that rule learning was controlled prior to performance. However, this rule training did not necessarily result in the children having an equivalent representation of rule-based information. Although rule learning scores were equal, 6-year old children required between 2 and 3 repetitions to learn the rules, i.e., significantly more attempts than 8-year olds who typically required only 1 or 2 repetitions. This indicates that the rule learning process was more effortful for 6-year olds, perhaps resulting in them having a less robust knowledge of the rules. This possibility appears to be confirmed by significant age group differences in rule memory, where children's knowledge of the rules was tested after they had played the multitask game. Therefore, it is possible that the rule learning of the two age groups was qualitatively different (via more repetitions) and that this impacted upon memory for these rules. This could lead to differences in children's knowledge of the retrospective content of prospective actions. It is difficult to see how to surmount this issue in developmental studies of to-be-remembered actions. Perhaps one way would be to simplify the rule-based information. Qualitatively, it seemed that younger children had
Chapter 6 – Multitask training study

more difficulty learning and retaining the concept of ‘full clusters get bonus points,’ whereas the concept of ‘yellow items are worth more points than blue’ was easier to learn. The ‘fill rule’ was developed to necessitate frequent between-task switching, to tap into the organisational and prospective memory systems underlying multitask performance. An alternative to this rule, but none the less retaining the necessity to switch between tasks, may be considered in future.

Given that rule learning was controlled prior to task performance, how did this manipulation impact upon 6 and 8-year old children’s scores on key multitask variables?

Rule training appears to have had a positive impact on children’s planning scores, which improved for both age groups. Plans made in the present study scored an average of 20% more points than plans made in the previous multitask study. Both aspects of planning were improved by rule training. Plans were more complex, as the majority of children generated a plan that included trying all three tasks. Likewise, strategic planning scores were also higher in the training study than in the previous multitask study. The positive impact of rule training on planning influenced both age groups to the same extent and in the present study no group differences were found in the quality of plans produced by 6 and 8-year old children. This result replicates the findings of the previous multitask study. This suggests that within the multitask paradigm, 6 and 8-year old children plan how to perform the paradigm at an equivalent level of complexity and with an equivalent level of strategic intent. Therefore, planning to perform multiple tasks may not develop significantly between 6 and 8-years of age. This is in contrast to evidence from the executive function literature suggesting that children’s planning skills undergo significant development between 6 and 8-years of age (Klahr & Robinson, 1981; Levin et al., 1991; Welsh et al., 1991). A possible explanation of these seemingly conflicting results is that planning in multitasking situations involves planning to perform multiple interleaved actions, whilst more traditional planning measures such as Tower tasks typically involve sequencing steps towards a single goal.

Planning scores were higher in the present training study than in the previous multitask study. It could be argued that children who participated in the present study were naturally better planners than children who participated in the previous multitask study. However, this explanation is unlikely as children in both studies were largely recruited from the same school, and planning scores improved by
as much as 20%. An alternative explanation is that rule training facilitated planning. The mechanism by which this could occur can be explained in terms of the Supervisory Attention System model (Shallice, 1988; Shallice & Burgess, 1996). Rule training increased children’s knowledge of the task demands and gave them a clearer idea of the goals of the multitask situation; this would facilitate the problem orientation phase and goal setting process within the SAS model. When the child is more familiar with the demands of the situation, it is easier to formulate a plan of how to perform multiple tasks.

In this training study, 6-year old children were significantly poorer at implementing the plans they had made (plan follow) than 8-year old children. In the previous multitask, study 6-year old children’s plan following scores were also lower than those of 8-year olds, and these differences also reached significance. In the previous multitask study, we proposed that 6-year olds were poorer at following their plan either because they did not understand the demands of the multitask, or because they lacked the ability to implement their plan. In the present study both 6 and 8-year old children were trained to learn the demands of the multitask situation, and this improved the quality of plans they produced but not their ability to follow through these plans; supporting the latter of these two explanations.

This lack of follow through is clearly illustrated in children’s multitask performance scores, which remained the same from the previous multitask study to the present study and were largely unaffected by rule training. Overall multitask performance scores were significantly different between the age groups. Significantly more 8-year olds attempted to perform all 3 tasks than did 6-year olds. These results were obtained in spite of broadly equivalent training on the rules governing the paradigm. This finding replicates the pattern of results obtained in the first multitask study whilst addressing concerns about age group differences in rule learning. As such, the results of the present study can be interpreted as reflecting age group differences in the ability to organise future actions.

The relationship between planning and multitask performance is illustrated in Figure 6.6. The z scores plotted demonstrate that 6-year old children’s performance was less proficient than their planning, whereas 8-year old children out-performed the plans they produced.
Six-year old children failed to implement the plans they produced: their plan following scores were significantly poorer than those of 8-year old children, as were their multitask performance scores. Only one aspect of 6-year olds multitask performance changed between studies: 50% of 6-year olds switched efficiently between tasks in the present study compared to only 20% in the previous multitask study. It is possible that this change can be accounted for by the improved planning scores observed in the present study. One aspect of forming a good plan involves generating more delayed intentions to switch between tasks. In the present study, almost all children explicated the intention to perform all three tasks without being prompted to do so, thereby setting up delayed intentions to switch between tasks. Moreover, 6-year olds in the present study implemented these delayed intentions as their self initiated task switching improved.

Given this improvement in task switching, why did children's multitask performance scores not improve? Task switching only constitutes a small part of the overall performance score, the major contributor is the strategic performance score which did not change following rule training. The strategic performance score measures how well children were able to use the rules of the task strategically to earn points. In both this training study and the previous multitask study, 6-year old children scored poorly on this measure. It is interesting to note that in the present study 6-year old children's strategic planning improved after rule training, as 60% of 6-year olds planned to 'do more yellow' or to 'fill things up' to earn more points. However, the children simply did not follow these intentions through - 6-year olds who said they would "do lots of yellow" appeared to forget this intention once they started performing the task. This either suggests a failure of supervisory system control, rather like the adult frontal lobe patients who formulate reasonable plans but then fail to implement them (Shallice & Burgess, 1991), or it suggests that children find the rules too difficult to use. We questioned whether young children were able to apply these rules at all, or if they were too challenging for them, despite their simplicity. We will address this question in the next study (Chapter 7) where we investigate the strategic rule use of 6 and 8-year old children on single rather than multiple tasks.

In contrast to 6-year olds, 8-year old children appeared to 'outperform' their plans, as they planned at a more basic level than they subsequently performed. What might explain this result? First, it is possible that 8-year old children simply did not verbalise all their intentions whilst planning, in future studies it would be advisable to emphasise to children that need to explain everything they intend to do. Second,
8-year old children might not have been able to plan a complex series of actions in advance, but may have realised a more efficient course of action during task performance. Observations of 8-year olds support both explanations. For example, some 8-year olds failed to make an explicit plan to prioritise yellow items, but as soon as they started to play the multitask game selected only yellow items. In addition, some 8-year olds began by attempting large clusters of items on one task but quickly realised this had been a poor choice, on the next task they selected a small cluster for completion earning more points. This second example indicates that 8-year olds may have been more skilled at monitoring their performance on-line and adjusting it accordingly.

Performance monitoring in the multitask paradigm is also measured by error making and rule breaking scores, for which no group differences were observed in either of our studies. In fact more children broke the one-by-one rule in the present study, indicating that greater familiarity with task demands does not protect against rule breaking behaviour. Similarly, rule training did not change scores on the recount variable, which measures the ability to monitor what was achieved during performance. In the present study 8-year old children scored more highly on this measure, although this difference failed to reach significance using non-parametric tests. In the previous multitask study we discussed how our recount measure might have been too simple to capture the prospective updating function it was intended to. However, it was kept the same in the present study to ensure maximum comparability between studies.

6.6 Summary of limitations and recommendations for future studies

We successfully trained children to learn the rules of the paradigm so that 6 and 8-year old children scored equally on our rule learning measure. However, despite best efforts, rule learning was not absolutely equivalent between 6 and 8-year old children. Six-year olds required a greater number of repetitions to learn the rules and recalled significantly less information about them post performance. The focus of our rule training procedure was on children's free-recall of the rules. In fact, what we wanted to enhance was children's understanding and knowledge of the task demands. In hindsight this could have been achieved differently, by teaching children the correct answers to cued questions about the task demands, rather than training them to rote learn four rules. There are also ways we could
have reduced memory load. For example in the Six Parts Test an instruction card containing information about the rules remains in view throughout task performance. The number of rules in our multitask paradigm is greater than in other children's paradigms. Whilst reducing the number of rules would reduce memory load, this should not be at the expense of rules encouraging switching between tasks. Finally, rule learning information is either not explicitly assessed in children’s multitask paradigms, or the results of any such assessment are not reported (Emslie et al., 2003; Martin & Kliegel, 2003; Siklos & Kerns, 2004). The fact that we measure rule learning and memory at all is a strength of our paradigm.

The mechanisms that underlie differences in 6 and 8-year old children's multitask performance remain unclear. Six and 8-year old children had not accomplished a level of fluent task switching, being just as likely to select an inefficient as an efficient switch strategy. This is indicative of an immature or developing prospective memory system. However, strategic rule use also shows significant group differences between 6 and 8-year olds. The ability to use the rules to earn points is dependent on strategy use, an executive function that develops in childhood (Anderson, Lajoie & Bell, 1995). It could be that performance differences in the rule training study are attributable to differences in children's ability to strategically use the rules. We shall investigate this question in our next study (Chapter 7) where we assess children's apply the same rules to the same tasks, outside of a multitask situation.

6.7 Chapter summary

The results of this training study replicate the results of the previous multitask study with one important difference; children achieved the same level of rule learning prior to performing the multitask paradigm, thus addressing the key limitation identified in the previous study. In spite of controlling rule learning, 6 and 8-year old children remained significantly different in their ability to perform the multitask paradigm. This finding is interpreted as a developmental difference in the ability to organise future behaviour. This difference may be attributable to developments in children's prospective memory and/or in their ability to strategically apply the rules of the paradigm. Rule training had a positive influence on children's planning. Although 6-year olds remained poor at implementing the plans they had formed, whilst 8-year olds appeared to out-perform the plans they had made, potentially due to a superior ability...
to adjust on-line performance in response to feedback. Rule training did not influence scores tapping into on-line monitoring skills including error making, rule breaking and recounting.
Chapter 7: Single task study

7

Single task study

In the previous two chapters we reported developmental differences in 6 and 8-year old children's multitask performance. Significant group differences were observed in how well 6 and 8-year old children were able to use the rules governing multitask performance to earn points. It is possible that these results do not reflect differences in children's ability to co-ordinate performance across multiple tasks. Instead, they may represent differences in how 6 and 8-year old children apply the rules governing performance to the individual tasks that comprise the multitask paradigm. To address this question a 'single task' study was set up in which a new sample of 6 and 8-year old children performed one of the three tasks that comprise the Battersea Multitask Paradigm.

7.1 Introduction

The results of the 6, 8 and 10-year old multitask study, reported in Chapter 5, indicated significant group differences between the performance of children of all ages on the multitask paradigm. In the training study, reported in Chapter 6, we explored the possibility that children's differential knowledge of the rules of the multitask paradigm could account for these developmental differences in performance. However, we were able to discount this hypothesis as age group differences in multitask performance persisted after children had learned the rules to a pre-set criterion. The question of what underlies these developmental differences remains unresolved. Two further possibilities are proposed. First, in
both the 6, 8 and 10-year old multitask study and the training study, 6 and 8-year old children did not consistently use the rules to facilitate performance and gain points. Therefore it is possible that developmental differences in multitask performance can in fact be accounted for by differences in how children apply the rules to individual tasks within the paradigm. Are the rules simply too challenging for 6 and 8-year old children to use? The second possibility is that group differences in performance can be accounted for by developmental differences in children's ability to co-ordinate performance across multiple tasks, reflecting the development of future organisation skills. In the present study we explore these possibilities further.

**7.1.1 Single task performance in children's multitask paradigms**

At face value it seems an obvious question: are developmental differences in multitask performance due, in all or in part, to developmental differences in performance on the single tasks that constitute multitask paradigms? This question is more relevant to our Battersea Multitask Paradigm than it is to other children's multitask paradigms such as the HEXE (Martin & Kliegel, 2003) or the Six Parts Test (Emslie et al., 2003), due to differences in task design and scoring.

In the HEXE multitask paradigm (Martin & Kliegel, 2003) children have 4 tasks to attempt in 5 minutes and tasks are divided into pairs (parts A and B). In the Six Parts Test (Emslie et al., 2003) children have 6 tasks to attempt in 6 minutes and tasks are also divided into pairs (parts 1 and 2). Two rules govern performance on both these paradigms: children should attempt some of each task before the time is out (the 'try all tasks' rule) and children should not perform both parts of a pair of tasks sequentially (the 'task order' rule). In the HEXE, performance is scored as the number of tasks that children attempt (adherence to the 'try all tasks' rule) and the number of times a child breaks the 'task order' rule. In the Six Parts Test performance is scored as the number of tasks the child attempts ('try all tasks' rule) minus the number of times the child breaks the 'task order' rule. In addition, the child's strategic use of these rules is evaluated: points are awarded if the child has adopted an obvious strategy to perform all 6 tasks within the time allowed (e.g., one task per minute, doing 3 items on each task), and if the child adopts an obvious strategy to adhere to the 'task order' rule (e.g., perform parts 1-1-1-2-2-2). What is not scored is the children's performance on the individual tasks themselves. Effectively, children could get each stimulus question wrong (e.g., maths questions, picture naming...
Chapter 7: Single task study

tasks) and it wouldn’t affect their final score. This is because the focus of the HEXE and the Six Parts Test is on how children co-ordinate performance across multiple tasks, rather than how they perform upon individual tasks. These tests are designed to measure multitasking ability in the absence of individual or developmental differences in single task performance.

In the Battersea Multitask Paradigm there is a greater emphasis on how flexibly children move between tasks and rather less focus on the number of tasks they attempt to perform. This has the advantage of assessing how children perform multiple interleaved tasks, moving from one to another and back again, as we do when multitasking in everyday life (Burgess et al., 2000; Shallice & Burgess, 1991). The Battersea Multitask Paradigm has 3 tasks and 4 rules. A ‘try all tasks’ rule is scored by measuring the number of tasks attempted, the same as in the HEXE and the Six Parts Test. In addition, the number of times the child switches between tasks is scored as inefficient or efficient (task switch score). The remaining 3 rules (‘yellow’, ‘fill’ and ‘one-by-one’) were designed to encourage children to switch flexibly between tasks: these rules are in place of the ‘task order rule’ of the HEXE and the Six Parts Test. What is unique about these 3 rules is that they can not only be applied across all tasks but within individual tasks as well. This was an important feature in the design of the Battersea Multitask Paradigm as it is using these rules both within and between tasks that encourages true interleaving. However, as well as being advantageous for switching, this feature raises the possibility that differences in children’s ability to apply these rules within tasks could account for developmental differences observed in multitask performance.

7.1.2 The single task study

The single task study was set up to test for the presence or absence of age group differences in children’s ability to apply the rules of the multitask paradigm within tasks as well as between them.

In the single task study each participating child performs 1 of the 3 tasks from the Battersea Multitask Paradigm. The key differences between single and multitask performance are that each child performs only 1 task within a time limit of 1 minute, and that there are only 3 rules to learn (the ‘try all tasks’ rule is redundant). Apart from reducing the demands of co-ordinating multiple intentions, the rules applied to the single task remain the same. Children must still apply the ‘yellow’ rule and the ‘fill’ rule to their
performance on the single task in front of them. They must also adhere to the 'one-by-one' rule, which remains tempting to break given the short time limit. In this way children's ability to strategically apply the same 3 rules to the same task can be evaluated, without the additional demands of multitasking.

New groups of 6 and 8-year old children were recruited to the single task study. It was not practical to carry out a within subjects manipulation of single versus multitasking, as asking a child to perform the multitask and a single task would reduce novelty and increase the likelihood of practice effects. Therefore we compare the results of the single task study to results obtained in the multitask training study (Chapter 6).
7.2 Aims and hypotheses

The aim of this study was to investigate 6 and 8-year old children's single task performance to address the following question: do group differences observed in multitask performance represent developmental differences in how children apply rules to the individual tasks comprising the multitask paradigm? Is 6 and 8-year old children's ability to use these rules within tasks different?

We hypothesise that children of both ages will be equally able to apply the 3 rules to single task performance. This is because:

- The rules are simple and easy to understand.
- Effective application of the rules is made explicit in the task instructions (e.g., 'it’s a good idea to do lots of yellow things' - 'it’s a good idea to choose things you can fill up' - 'so 1 in your hand, not 2').
- Both 6 and 8-year old children were able to apply these rules, albeit somewhat inconsistently, during multitask performance.
- Age group differences in multitask performance represent developmental differences in children’s ability to organise and sequence multiple intended future actions, rather than differences in how well children are able to apply the rules within tasks.
Chapter 7: Single task study

7.3 Method

7.3.1 Study design

This study is a cross-sectional, between-subjects factorial design. There are two factors (age group and task performed) and no repeated measures. The six participant groups are outlined in Table 7.1.

Table 7-1: Two-factor between-subjects factorial design

<table>
<thead>
<tr>
<th>Levels of Age Factor</th>
<th>Levels of Task Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beads</td>
</tr>
<tr>
<td>6-years</td>
<td>Group 1</td>
</tr>
<tr>
<td>8-years</td>
<td>Group 4</td>
</tr>
</tbody>
</table>

7.3.2 Ethical considerations

This study was covered by ethical approval granted for previous studies. Schools were recruited and letters sent home with every child in a chosen school class. Parents were sent an information letter and consent form and given ample opportunity to ask questions or to contact the researcher by telephone. Written parental consent and the child's verbal assent were obtained for every child who participated in the study. As described previously, children received a certificate and a small prize as a token of thanks for their participation. School classes received book tokens.

7.3.3 Participants

Recruitment

Children were recruited from a mainstream primary school that had not participated in any of our previous studies. The head teacher was asked to give permission for children in his school to participate and with his endorsement, letters were distributed to parents of children in target year-groups and collected by class teachers. A one-week block of testing was arranged during which the researcher tested as many children as possible (see response rates below).
Response rates

Three classes from each school year participated in the study. There were approximately thirty children in each class. Of the ninety letters sent home to parents of 6-year olds, 64 were returned of which 61 granted consent. Of the ninety letters sent home to parents of 8-year olds, 59 were returned of which 56 granted consent. Due to the impressive response rate, eleven 6-year old children and three 8-year old children whose parents consented could not be assessed within the confines of the test schedule. These children received a small prize and short written note thanking them for their interest. A total of 50 six-year olds and 53 eight-year olds were assessed.

7.3.4 Procedure

Test environment

One third of test sessions were conducted in a quiet room in the school, the remaining two thirds of children were tested at the end of a quiet corridor in an annexe building. The researcher collected and returned each child to and from class. During the session the child was seated at a table opposite the researcher. The single task was laid out on the table directly in front of the child.

Test administration

The total testing time was 10 minutes. At the end of the session children were thanked, given a certificate and a small prize and accompanied back to their classroom.

The administration procedure for the single task study was closely modelled on the multitask administration. To ensure everything was a similar as possible between the multitask and single task studies, the single task study included the same six administration stages: learn, plan, plan follow, perform, recount and remember. The main difference is that in the single task study children performed only one task under a one-minute time limit and had 3 rather than 4 rules to learn. Detailed instructions for single task administration are provided in Appendix 4 and changes are summarised briefly below.

The children were introduced to their allotted single task and learned how to 'play the game' using the same practice materials as for the multitask. Once they had learned how to play the practice game,
children were shown the apparatus for the ‘real game’ and introduced to the rules of the game and the time limit. The single task has only three rules: ’yellow more points than blue,’ ‘bonus points for filling things up’ and ‘pick things up one-by-one,’ as the ‘try all 3 tasks’ rule of the multitask is redundant. This is also reflected in the cued questions about children’s knowledge of the rules, two questions were omitted: ‘how many games are there?’ and ‘how many games should you try?’ In the single task study children had to be able to repeat all three rules prior to performing the task and each child was given up to three opportunities to learn these rules. Children who failed to learn the 3 rules were excluded from further analyses. A time limit of 1 minute was set for single task performance; in the multitask study children had 3 minutes in which to attempt 3 tasks; it follows that they would have 1 minute to perform 1 task. As in the multitask game, a sand timer (1 minute) gave children a visual representation of the time limit. Following rule learning, children proceeded through the next five stages of task administration (plan, plan-follow, perform, recount and remember). At each stage scoring was adapted to incorporate a single rather than multiple task (see Appendix 4).

The variable of interest in the single task study is task performance. Single and multitask performance scores are summarised in Table 7.2. Single task performance is a composite variable comprised of two contributing scores: a strategic rule use score and a penalty performance score. Multitask performance is also a composite variable comprised of three contributing scores: a strategic rule use score, a penalty performance score and a task switch score. The single task score is derived in a very similar way to the multitask performance score with the exception that the task switch score is not relevant in the single task study. The task switch measures the efficiency with which children switch between the 3 tasks and represents the multitask demands of the paradigm. Single task performance is isolated from these multitask demands, therefore there is no equivalent score.
Table 7-2: Scoring criteria for single and multitask performance

<table>
<thead>
<tr>
<th>Single Task</th>
<th>Score</th>
<th>Multitask</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of tasks attempted</td>
<td>0 to 1</td>
<td>Number of tasks attempted</td>
<td>0 to 3</td>
</tr>
<tr>
<td>Single yellow item first</td>
<td>0 to 1</td>
<td>Single yellow item first</td>
<td>0 to 3</td>
</tr>
<tr>
<td>Yellow prioritised overall</td>
<td>0 to 1</td>
<td>Yellow prioritised overall</td>
<td>0 to 3</td>
</tr>
<tr>
<td>Cluster full before move to next cluster</td>
<td>0 to 1</td>
<td>Cluster full before move to next clusters</td>
<td>0 to 3</td>
</tr>
<tr>
<td>Item placed on small cluster first?</td>
<td>0 to 2</td>
<td>Item placed on small cluster first?</td>
<td>0 to 6</td>
</tr>
<tr>
<td>Single Task Strategic performance</td>
<td>0 to 6</td>
<td>Multitask Strategic Performance</td>
<td>0 to 18</td>
</tr>
<tr>
<td>Is the 1-by1 rule is broken?</td>
<td>-1 to 0</td>
<td>N tasks on which 1-by-1 rule is broken</td>
<td>-3 to 0</td>
</tr>
<tr>
<td>Are errors are made?</td>
<td>-1 to 0</td>
<td>N tasks on which errors are made</td>
<td>-3 to 0</td>
</tr>
<tr>
<td>Penalty performance score</td>
<td>-2 to 0</td>
<td>Penalty performance score</td>
<td>-6 to 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multitask switch score</td>
<td>-2 or +2</td>
</tr>
<tr>
<td>Single Task Performance Composite</td>
<td>0 to 6</td>
<td>Multitask Performance Composite</td>
<td>0 to 20</td>
</tr>
</tbody>
</table>
Chapter 7: Single task study

7.4 Results

7.4.1 Exploration of the data

Cases excluded from analyses

A total of 103 children were assessed, 50 six-year olds and 53 eight-year olds. 11 children failed to learn all 3 rules after three attempts to do so. Seven of these children were 6-years old (2 male, 5 female) and four were 8-years old (1 male, 3 female). Of the 6-year olds excluded: 1 performed the Beads task, 2 the Caterpillars task and 4 the Counters task. Of the 8-year old children excluded: 1 performed the Beads task, 1 the Caterpillars task and 2 the Counters task. These children were allowed to ‘play’ the game under timed conditions and received a certificate and a prize like other participants, however they were excluded from subsequent analyses.

Sample characteristics

92 children were included in this study: a 6-year old group (N = 43) and an 8-year old group (N = 49). Distribution of ethnic diversity was equal with approximately 90% of children in each being Caucasian: 6-year olds (39 Caucasian, 2 Asian and 2 Mixed Race) and 8-year olds (47 Caucasian, 1 Asian and 1 Mixed Race). Sample characteristics are summarised in Table 7.3.

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Age (years, months)</th>
<th>SD (months)</th>
<th>Range (months)</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-years (43)</td>
<td>6y 6m</td>
<td>4.73</td>
<td>72 - 89</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>8-years (49)</td>
<td>8y 8m</td>
<td>3.73</td>
<td>97 - 113</td>
<td>26</td>
<td>23</td>
</tr>
</tbody>
</table>

Single task performed

We wanted approximately one third of children in each group to perform each of the three single tasks. To ensure this was achieved we alternated the order in which single tasks were administered, so that if one child performed the Beads task the next child would perform the Counters task etc. This process
also prevented all the children in one school class performing the same task. The number of children in each age group who performed each task is approximately equal, Table 7.4.

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Bead Task</th>
<th>Caterpillar Task</th>
<th>Counter Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-years (43)</td>
<td>16</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>8-years (49)</td>
<td>17</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Totals (92)</td>
<td>33</td>
<td>30</td>
<td>29</td>
</tr>
</tbody>
</table>

### 7.4.2 Age by task comparisons

The purpose of the single task study was to investigate single task performance. First, we compared the performance of children in each age group on the three single tasks to investigate whether differences in age or task type influenced single task performance. The performance of 6 and 8-year old children on each of the three tasks is illustrated in Figure 7.1.

*Figure 7-1: Age group single task performance*
A between-subjects analysis of variance was calculated with 'task performed' and 'age' as grouping variables. Results revealed a significant main effect of task type on single task performance \( [F (2,91) = 4.43, p< .05] \), but no significant main effects of age group on single task performance \( [F (1,92) = 0.48, \text{NS.}] \) and no significant age-by-task interaction \( [F (2,91) = 0.63, \text{NS.}] \). The significant main effect of task type on single task performance indicates that the single tasks are not of equivalent difficulty to one another. The results illustrated in Figure 7.1 indicate that children in both age groups performed less well on the Beads task. Follow up Tukey HSD tests confirmed that this difference was between the Beads task compared to the Caterpillar and Counters tasks \( (p < .05) \). No significant main effects of age group on single task performance were found. The mean performance results in Figure 7.1 do not indicate large performance differences between 6 and 8-year old children on any of the single tasks. This supports the experimental hypothesis that 6 and 8-year old children would be equally able to apply the rules to single task performance. There was no significant age-by-task interaction indicating that task difficulty does not interact with age: 6-year old children did not find any single task more difficult than 8-year old children. Although the Beads task was more difficult than the other single tasks, both 6 and 8-year olds found it more difficult. This non-significant interaction means that performance on each single task can be grouped together for further comparison.

### 7.4.3 Single task performance

As single task difficulty did not interact with age, we were able to group children who had performed these different tasks together into a '6-year old single task group' and an '8-year old single task group.' We compared the performance of these two age groups on the composite single task performance score, the strategic single task performance score and the penalty single task performance score. No age group differences were observed on any of these scores. These results support our hypothesis that 6 and 8-year old children would be equally able to perform the tasks under single task conditions. The scores of 6 and 8-year old children on all three of these aspects of single task performance are detailed in Table 7.5.
Table 7-5: Single task performance scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Composite Single Task Performance Score (0-6) Mean (SD)</th>
<th>Strategic Single Task Performance Score (0-6) Mean (SD)</th>
<th>Penalty Single Task Performance Score Errors</th>
<th>N children</th>
<th>Rule Breaks N children</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-years (43)</td>
<td>4.28 (1.31)</td>
<td>4.37 (1.33)</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>8-years (49)</td>
<td>4.47 (1.49)</td>
<td>4.55 (1.37)</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

No age group differences were observed for the composite single task performance \([F (1,90) = 0.42, \text{ NS.}]\) which represents how well the children performed the single task. The strategic single task performance score reflects children's strategic use of rules to gain points and no age group differences were observed for this score either \([F (1,90) = 0.40, \text{ NS.}]\). Finally very few children in either group made performance errors or broke the one-by-one rule. Only one 6-year old and three 8-year olds made placement errors that they did not correct and three 6-year olds and one 8-year old broke the one-by-one rule. We observed that all errors and rule breaks were committed on the Beads task.

### 7.4.4 Comparing single to multitask performance

How does children's single task performance compare to their multitask performance? The aim of the single task study was to evaluate how well children apply the rules of the game to performing a single task, without the added demands of applying these rules across multiple tasks. How did children's performance compare across the single and multiple task studies? Single task results are compared to multitask results obtained in the multitask training study (Chapter 6).

**Comparing composite performance scores**

In the multitask there are 4 rules to apply to 3 tasks, in the single task there are 3 rules to apply to 1 task. The multitask is more complex and demanding than the single task. The composite multitask performance score represents strategic, penalty and switching scores, the single task composite score represents strategic and penalty aspects of performance only. Six and 8-year old children's single and multitask composite performance scores are illustrated in Figure 7.2. Scores are described as percentages.
It is clear that the performance of both 6 and 8-year old children was less successful under multitask conditions. Six-year old children's performance suffered most under multitask conditions, although 8-year olds were still not as performing at the same level as they did during single task performance, indicating that they also found the multitask situation challenging. It is interesting to note that 10-year olds in the first multitask study (Chapter 5) scored at an average level of 75% on the multitask composite score, which is close to the level of performance achieved by 6 and 8-year olds during single task performance.

Comparing strategic performance scores

By comparing strategic performance scores we can evaluate how well children were able to strategically apply the rules to gain points during task performance. We wanted to investigate whether 6 and 8-year old children found it difficult to use rules such as the 'yellow' rule and the 'fill' rule. Figure 7.3 illustrates the strategic performance scores of 6 and 8-year old children under single and multiple task conditions. The results clearly indicate that under single task conditions 6 and 8-year old children are able to use the rules to govern task performance, it is only under multitask conditions that this becomes more challenging and age group differences are observed. Under single task conditions 6
and 8-year old children scored just over 70% of possible points, however under multitask conditions 8-year olds' performance dropped to 60% and 6-year olds' performance dropped to 50%.

Figure 7-3: Strategic performance in single & multitask studies (in %)

Comparing penalty performance scores
In the single task study very few children made any uncorrected errors, a similar pattern of results was observed in the multitask study. In contrast, children performing the multitask were far more likely to break the 'one-by-one' rule than children performing the single tasks. In the multitask training study up to 50% of children broke this rule compared to only 5% in the single task study. It is possible that children in the multitask study were tempted to break the rules in order to fill an item as quickly as possible before moving on to another task. Alternatively, differences in the processing demands of multiple versus single task performance might have had a strong impact on rule breaking behaviour. Both possibilities will be discussed further. The percentages of children in each age group who made errors or broke the rules under single and multitask conditions are illustrated in Figure 7.4.
Figure 7-4: Children who broke rules and made errors during single and multitask performance (in %)
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7.5 Discussion

In this study we explored the possibility that age group differences observed in multitask performance could be explained by age group differences in single task performance. No age group differences in single task performance were found. Six and 8-year old children were equally able to strategically apply the rules to a single task and made very few performance errors or rule breaks. This result contrasts with significant age-related differences observed in multitask performance. As children are able to perform the tasks singly, it is likely that group differences in multitask performance represent developmental differences in children’s ability to co-ordinate and sequence multiple intended actions. This interpretation of the results is discussed further below.

The single task study provided a unique opportunity to contrast performance on the different single tasks within age groups. Approximately equal numbers of children in each age group performed the single tasks, results indicated that performance on the Beads task was significantly more difficult than performance on the other two tasks (Caterpillars and Counters). It may be more difficult to apply the ‘fill’ rule to the Beads task, as pots of Beads are larger and therefore take longer to fill. Related to this, the temptation to break the one-by-one rule may be stronger in the Beads task precisely because pots take longer to fill: Beads was the only task on which children broke this rule. Both 6 and 8-year old children found the Beads task more challenging than the Caterpillars or Counters tasks hence no age-by-task interaction was found. The lack of a significant age-by-task interaction meant that children who had performed different single tasks could be grouped by age for further analyses.

No age group differences were found for any aspects of single task performance, confirming our hypothesis that 6 and 8-year old children would be equally able to perform the single tasks. Both groups of children were equally able to apply the rules to gain points during single task performance; each scored an average of 70% on the strategic performance measure. Likewise, no age group differences were observed for aspects of performance on which children could be penalised; very few children broke the one-by-one rule or made placement errors during single task performance.
This lack of age group differences in children’s single task performance contrasts with the significant age group differences observed in 6 and 8-year old children’s multitask performance. Whilst 6 and 8-year old children were able to perform the single tasks at an equivalent level, their task performance declined under multitask conditions. In terms of overall performance: 6-year olds scored an average of 70% of performance points on the single task compared to just 50% on the multitask. Similarly 8-year olds’ performance was poorer under multitask conditions, falling from 70% on the single task to 60% on the multitask. Both groups of children applied the rules (‘yellow’ and ‘fill’) equally well in the single task but their performance suffered in the multitask as they failed to score as many strategic performance points. In the single task study only 2-5% of children broke the one-by-one rule whilst in the multitask training study 50% of 6-year-olds and 38% of 8-year-olds broke this rule. It may have been more tempting to try to fill an item before switching to another task, or the cognitive demands of multitasking may have stretched children’s limited capacity processing resources to the extent that they were less able to inhibit rule breaking. In the single task study processing demands were lower and few children broke the rule.

It is clear from these results that 6 and 8-year old children were able to successfully apply rules to gain points, and to inhibit breaking these rules when performing a single task. However, when they were required to apply the same rules to multiple tasks their performance broke down. Why was multitasking so challenging for 6 and 8-year old children?

Multitasks are designed to tap into the cognitive abilities necessary to co-ordinate and organise the performance of multiple future actions. Multitask performance relies on a complex set of cognitive abilities including prospective memory and executive functions (e.g., Bisiacchi, 1996, 2000; Burgess, 2000; Ellis, 1996; Kliegel et al., 2002; Martin & Schumann-Hengsteler, 2001). The role of executive functions in the organisation of future actions is to prioritise, co-ordinate and sequence multiple intentions, (Kliegel et al., 2002; Martin & Schumann-Hengsteler, 2001) and prospective memory plays a key role in the creation and activation of delayed intentions (e.g., Burgess et al., 2000; Ellis, 1996). Associations between prospective memory and executive functions have been reported in typically developing adults (e.g., Cherry & LeCompte, 1999; Kliegel et al., 2002; Kopp & Thone, 2000; McDaniel & Einstein, 2000) and children (Baressi, 2001; Guardardo & Best, 2000; Martin & Kliegel., 2003).
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"...working memory capacity predicts significant amounts of the variance in prospective memory performance" (Kliegel et al., 2002, page 304). The interaction between working memory, executive functions and prospective memory in the organisation of future behaviour is captured in the Supervisory Attentional System (SAS) model of action control (Norman & Shallice, 1986; Shallice, 1988; Shallice & Burgess, 1996). Future behaviour is made possible by this system wherein multiple intentions are formed, delayed and executed at appropriate points in future time, within the confines of a limited capacity processing space.

The Battersea Multitask Paradigm taps these cognitive abilities. Specifically, task switching places demands upon prospective memory and executive functions involved in the co-ordination of multiple future actions (e.g., Burgess et al., 2000; Kliegel et al., 2000; Martin et al., 2003), strategic rule use requires executive abilities (Shallice & Burgess, 1991; Martin et al., 2003) and rule breaking taps inhibition functions (Burgess et al., 2000; Shallice & Burgess, 1991). Multitask performance places demands on the co-ordinated interaction of these various cognitive processes in the SAS. It also places a heavier load on the limited capacity working memory system by requiring a greater volume of information to be stored and processed.

We propose that developmental differences in multitask performance are observed because the ability to combine performance across multiple tasks develops through childhood as the SAS matures. Our results provide evidence to support this assertion, as children were able to perform the tasks individually in a single task study but their performance declined under multitask conditions. Compared to multitasking, single task performance makes no demands on the cognitive processes involved in the organisation and realisation of multiple delayed intentions and places fewer storage and processing demands.

It is likely that developments in prospective memory (Kerns, 2000; Kvavilashvili et al., 2001; Martin & Kliegel, 2003; Meacham & Colombo, 1980), executive functions (Anderson et al., 1995; Emslie et al., 2003; Levin et al., 1991; Welsh et al., 1991) and working memory (Gathercole, 1998, 2004; Siegel, 1994) in childhood support the development of the ability to organise future behaviour. Furthermore the SAS is mediated by the frontal lobe region of the brain (Burgess, 2000; Burgess et al., 2000, 2001,
2003; Shallice, 1988), which undergoes protracted development throughout childhood (Giedd et al., 1996, 1999; Sowell et al., 2001, 2003), providing a biological basis for the development of future oriented behaviour.

7.6 Limitations and future studies

We were limited to comparing single and multitask performance between studies, this is not ideal as data were collected from different participant groups in separate studies. However, it would have been difficult to compare single and multitask performance within subjects, as performing a single task test in advance would reduce novelty and influence multitask performance, and vice versa.

The children recruited to both studies were sampled from mainstream schools in similar socio-economic areas. Unfortunately, due to the time of testing within the school calendar year, children who performed the single task study were slightly older than those who performed the multitask training study. However, the magnitude of age-group differences remained the same across both studies, i.e., 24 months difference between 6 and 8-year old participants.

The strategic application of large number of rules to a comparatively small number of tasks is a facet of Battersea Multitask Paradigm performance that is intrinsically different to other children's multitasks. This difference in task design may in fact give greater scope for identifying age-related differences in performance. Unlike performance on another children's multitask paradigm which tended to near ceiling around 11-12 years of age (Martin & Kliegel., 2003), results from the first Battersea Multitask Paradigm reported in Chapter 5, indicated that 10-year olds were not performing near ceiling. We believe that the Battersea Multitask Paradigm may prove sensitive to developmental differences in older children and possibly adults. This will be investigated in the next study (Chapter 8) where we administer the Battersea Multitask Paradigm to a sample of 14-year old adolescents and young adults.
7.7 Chapter summary

The purpose of the single task study was to evaluate whether group differences in 6 and 8-year old children’s multitask task performance could be accounted for by age differences in the way children performed the individual tasks comprising the Battersea Multitask Paradigm. No age group differences in single task performance were observed. Results support the hypothesis that group differences in multitasking are due to developmental differences in children’s ability to sequence and co-ordinate multiple intentions.
Chapter 8: Multitasking in adolescents and young adults

Multitasking in adolescents and young adults

We have reported developmental differences in the multitask performance of children aged 6, 8 and 10-years. These results have been interpreted as representing developmental differences in children's ability to organise future actions. We observed that 10-year old children did not score at ceiling during multitask performance, indicating that our Battersea Multitask Paradigm could be used to investigate further developments in multitasking skills. The present study was designed to investigate the continued development of the organisation of future behaviour in adolescents and young adults. We assessed the performance of 14-year olds and young adults on the Battersea Multitask Paradigm.

8.1 Introduction

The aim of this study was to investigate the continuing development of the organisation of future actions in adolescence and young adulthood. There are good reasons to expect further developments in future organisation skills: (1) the cognitive skills underlying the organisation of future actions develop through adolescence into adulthood, (2) the protracted maturation of the prefrontal cortex provides a biological basis for this development and (3) the Battersea Multitask Paradigm is a measure sensitive enough to capture this continued development through its detailed scoring system. Evidence for these three points is considered below, following which we generate hypotheses about the performance of 14-year olds and adults on the Battersea Multitask Paradigm.
8.1.1 The continuing development of future organisation skills

Children continue to develop their future organisation skills as they move into adolescence and ultimately into young adulthood, becoming increasingly autonomous agents in their own lives as they take control of work or study commitments and organise social activities. The organisation of future behaviour is underpinned by a specific set of cognitive abilities including prospective memory, retrospective memory, working memory and executive functions. There is a body of evidence that supports the continued development of these cognitive abilities into adolescence and even young adulthood. This evidence is reviewed below.

Prospective memory in adolescence and adulthood

Only three studies have investigated prospective memory skills in children older than 10-years of age, one evaluated event-based prospective memory skills (Passolunghi et al., 1995) and two assessed time-based prospective memory skills (Ceci & Bronfenbrenner, 1985; Kerns, 2000). Passolunghi and colleagues (1995) reported significant age group differences in performance on a time-based prospective memory task, with 10 to 11-year old children consistently out-performing 7 to 8-year old children. Similarly, children aged 11 and 12-years performed a computerised time-based prospective memory task more successfully than 7 to 10-year old children (Kerns, 2000). Fourteen-year old children are likely to adopt strategies to facilitate time-based prospective remembering and more able to flexibly transfer these strategies across different testing environments (home versus laboratory) than 10-year old children (Ceci & Bronfenbrenner, 1985). Overall, results indicate that prospective memory continues to develop beyond 10-years of age, in all three studies older children outperformed their younger counterparts. Studies of time-based prospective memory in particular indicate that older children’s success may stem from their increased likelihood to adopt an efficient strategy to remember intentions in both novel and familiar environments.

Prospective memory in adults is a sophisticated, highly developed cognitive ability (e.g., McDaniel & Einstein, 2000; Kliegel et al., 2002). Studies of prospective memory in adulthood have shown that prospective remembering occurs within a limited capacity system and can be automatically or voluntarily controlled via the use of memory cues. Performance on prospective memory tasks is influenced by the salience of these clues relative to the level of absorption in the ongoing activity and
the importance of the to-be-remembered activity (Brandimonte & Passolunghi, 1994; Kliegel et al., 2001; McDaniel & Einstein, 2000). In addition to establishing how prospective memory operates in adulthood many experimenters have focused on comparing prospective memory in younger and older adults. Age related reductions in prospective memory have been reported, when the prospective memory task is highly demanding performance on the ongoing task may suffer (e.g., Craik & Kerr, 1996; Maylor, 1993, 1996). Adult studies indicate that prospective memory ability peaks in young adulthood and is likely to evidence declines in later life (e.g., Craik & Kerr, 1996).

The Battersea multitask paradigm places demands on prospective memory in a novel, non-routine test situation. The most direct measure of prospective memory in the multitask paradigm is the task switch score. A more indirect measure of prospective memory is reflected in the overall multitask performance score. In light of the evidence considered above we anticipate further developments in multitask performance through adolescence into young adulthood. These changes are expected for both the ‘task switch score’ and the overall ‘multitask performance score.’

**Retrospective memory in adolescence and adulthood**

As we discussed previously, the role of retrospective memory in the organisation of future action is to store the content of a to-be-performed action in memory until the action is performed (Einstein & McDaniel, 1990). There is evidence that retrospective memory continues to develop through adolescence into young adulthood (Cowan, Nugent, Elliott et al., 1999; Schneider, 2002). The increased use of strategies to remember information is likely to account for major changes in retrospective memory between young childhood and adolescence (Schneider, 2002). For example organisational strategies develop during this period, such as grouping words in a list by semantic category (e.g., Schneider & Sodian, 1997). Sowell and colleagues (Sowell, Delis, Stiles et al., 2001) investigated delayed memory for word lists in relation to structural brain changes measured by MRI in children and adolescents. They reported a strong relationship between maturation of frontal lobe gray matter and improvements in retrospective memory functioning; thereby supporting the possibility that increased use of memory strategies mediated by the frontal lobes contributes to developments in retrospective memory in late childhood and adolescence.
The retrospective memory demands of the Battersea Multitask Paradigm involve learning and remembering the four rules governing task performance. During multitask administration, retrospective memory for these rules is assessed via free and cued recall, before and after multitask performance.

Despite the evidence reviewed above supporting the development of retrospective memory in adolescence and young adulthood, we did not expect these changes to impact upon the retrospective memory scores of the Battersea Multitask Paradigm. This is because we designed the rules of the paradigm to be easy to learn and retain. The 10-year old children in our previous study (Chapter 5) scored very highly on rule learning and rule memory measures and we expect 14-year olds and adults to do the same. What is interesting is that the evidence reviewed above indicates that retrospective memory changes from late childhood into adolescence are influenced by developments in strategy use. Strategy use is a type of executive function, in the multitask paradigm developmental differences in strategy use are more likely to influence multitask performance scores than retrospective memory scores. The influence of executive functions on multitask performance is discussed shortly.

**Working memory in adolescence and adulthood**

Developments in working memory are likely to influence multitask performance in adolescents and young adults. Working memory capacity limits the processing space available for the cognitive processing involved in the organisation of future behaviour (Graf & Uttl, 2001; Shallice & Burgess, 1996). Evidence from a number of studies demonstrates that working memory continues to develop into the adolescent years (Case, Kurland & Goldberg, 1982; Gathercole, 1998; Gathercole et al., 2004; Siegel, 1994). In a life span study investigating working memory performance as a function of age, performance scores increased steeply from 6 to 13-years of age, followed a more shallow slope into young adulthood and only began to evidence gradual decline after 45 years of age (Swanson, 1999).

Improvements in complex working memory performance are attributed to the increasing efficiency of the developing central executive component of working memory (Gathercole et al., 2004). The central executive has been compared to the Supervisory Attention System (SAS) model of action control (Goldman-Rakic, 1998) and recent conceptualisations of the central executive have been strongly influenced by the SAS model (Baddeley & Della Sala, 1998). In turn, the functioning of the supervisory system is limited by working memory capacity (Shallice & Burgess, 1996).
Performance on the Battersea Multitask Paradigm is dependent on the functioning of the SAS model of action control, which is limited by working memory capacity. As working memory continues to develop through adolescence and into young adulthood there is good reason to predict further developmental changes in multitask performance in the 14-year old children and young adults who will be tested in this study. Specifically, we expect 14-year olds overall multitask performance to be different from that of young adults.

Executive functions in adolescence and adulthood

Research has shown that different executive functions develop along different trajectories through early and middle childhood and into adolescence, supporting a stage-like maturation of executive functions (e.g., Becker et al., 1987; Passler et al., 1985; Levin et al., 1991; Welsh et al., 1991). By the beginning of adolescence, age 10 to 12-years, some executive functions are better developed than others. Inhibition and attention control skills evidence have reached a near adult like state of maturation by age 12-years (Anderson, 2002; Levin et al., 1991). Likewise cognitive flexibility, measured by performance on two-dimensional set-shifting tasks such as the Wisconsin Card Sort Test, is well developed by age 12-years, nearing adult levels of performance (e.g., Anderson, 1998; Chelune & Baer, 1986; Levin et al., 1991; Welsh et al., 1991). In contrast problem solving, planning and strategy use are not fully developed by 12 years of age and continue to show functional gains into later adolescence (Anderson, 1998; Anderson et al., 1995; Levin et al., 1991). Levin and colleagues included a group of 13 to 15-year old children in their original study of the normative development of executive functions (Levin et al., 1991). The performance of children aged 13-15-years continued to improve on tests of strategy use, (clustering words during a word list learning test); organisation (producing novel designs in a design fluency task); and planning and problem solving (tested by performance on the Tower of London test).

Two more recent studies were specifically designed to investigate the development of executive functions in adolescence (Anderson, Anderson, Northam et al., 2001b; Davies & Rose, 1999). Children aged 11 to 17-years performed multiple executive function tests (Anderson et al., 2001b). Results supported a ‘gradual trend’ for the development of attentional control through adolescence with a spurt in attentional capacity in late adolescence (15-years plus). Processing speed also developed during
Chapter 8: Multitasking in adolescents and young adults

this period, older adolescents (15-years plus) processed information more rapidly than younger adolescents did (11-13 years). There was little change in performance on a test of sustained attention throughout the 11-17-year age group, indicating that this skill is well developed prior to adolescence. Performance on tests of cognitive flexibility showed a much more stable and even pattern of performance across adolescence with little evidence of developmental change, a pattern that fits the evidence discussed earlier supporting the maturation of cognitive flexibility by 12-years of age. Planning and problem solving skills showed evidence of a continued slow and gradual developmental progression from 12 to 17 years of age, 11-year old children showed markedly different planning to elder peers, in contrast to more gradual increments in planning observed amongst older adolescents (Anderson et al., 2001b). Again this corresponds to the results discussed above where planning skills had not reached maturity by age 12-years of age. Planning and problem solving abilities in 'abstract space' continue to develop into adulthood (Klahr, 1994; Klahr et al., 1993).

Davies and Rose (1999) investigated the relationship between the maturation of the prefrontal cortex and cognitive test performance during adolescence. They reported greater developmental gains on tests of frontal lobe function than on tests of parietal lobe function, in accordance with greater neurological development of the frontal region during adolescence. These authors also assessed possible influences of gonadal hormones on cognitive performance. Rather than investigate progression on tests of executive function across age groups, they grouped participants into one of three stages: pre-pubertal, mid-pubertal and post-pubertal. Male participants’ performance on frontal lobe tests changed significantly between pre-puberty and mid-puberty. Female participants' performance on some tests changed between pre-puberty and mid-puberty, whilst on other tests differences were observed between mid-puberty and post-puberty. Results indicate that both brain and hormonal changes may underpin cognitive changes in adolescence.

Finally, evidence from a life span study supports the development of executive functions into young adulthood (De Luca, Wood, Anderson et al., 2003). In this study the CANTAB battery of executive function tests was used (Cambridge Neuropsychological Test Automated Battery: Owen, Downes, Sahakian et al., 1990). Significant periods of development on four tests of executive function were observed in adolescence (aged 15-19 years) and again in young adulthood (aged 20-29 years). Both
age groups demonstrated similarly successful performance on a working memory task, although 20-29-year old adults used more efficient strategies to reach a solution. A similar result was obtained for strategy use in an executive problem solving tower task, where 15-19-year olds and young adults scored a higher percentage of correct solutions than younger participants (8-14-years), indicating superior strategic planning of goal-directed behaviours (De Luca et al., 2003).

In sum, executive functions continue to develop through adolescence and into young adulthood. Although some executive skills have matured by 12-years of age, many continue to evidence further gradual developmental gains in adolescence. Goal-directed problem solving and strategy use continue to improve into young adulthood. Executive functions are involved in the organisation of future actions and are likely to influence performance on the Battersea Multitask Paradigm. On the basis of the evidence reviewed above, we expect developmental differences in multitask performance between 14-year olds and young adults. These differences are most likely to be represented in scores reliant upon executive skills, such as the strategic performance score.

**Summary of the continuing development of future organisation skills**

The evidence reviewed in this section supports our hypothesis that the ability to organise future behaviour continues to develop into adolescence and young adulthood. The cognitive processes involved in the organisation of future behaviour develop between childhood and young adulthood. These developmental changes may be more gradual than those observed in middle childhood, however they do occur. The importance of adolescence for the development of cognitive skills dependent on the prefrontal cortex (such as future organisation skills) is underpinned by the substantial maturation of this brain region between late childhood and young adulthood. Evidence for this brain development is considered below.

**8.1.2 Maturation of the prefrontal cortex in adolescence and adulthood**

The functioning of the prefrontal cortex has been linked to the organisation of future actions (Bechara et al., 2000; Duncan et al., 1995; Shallice & Burgess, 1991), prospective memory (Bisiacchi, 1996; Burgess et al., 2000, 2001, 2003; Leyes et al., 2003; McDaniel et al., 1999), working memory's central executive (Colette & Van der Linden, 2002; D'Esposito et al., 1995; Duncan & Owen, 2000) and
executive functions (Fuster, 1989, 1998; Tranel et al., 1994). "The prefrontal cortex is the seat of one overriding system – the supervisory system" (Shallice & Burgess, 1998, page 22). The protracted development of the prefrontal cortex provides a biological substrate for the ongoing maturation of the organisation of future actions. A great deal of evidence indicates that the prefrontal cortex continues to develop into young adulthood. Indeed, the period from late childhood through adolescence into young adulthood is now accepted as an important developmental period during which the prefrontal region of the brain undergoes a number of important structural and corresponding functional changes.

**Structural changes**

The structural development of the prefrontal cortex continues well into young adulthood (Fuster, 1989, 1998; Giedd et al., 1996, 1999; Klingberg et al., 1999; Pfefferbaum et al., 1994; Rubia et al., 2000; Yakolev & Lecours, 1967). Evidence from a recent longitudinal MRI study indicates that the higher-order association cortices such as the prefrontal cortex mature later than lower-order somatosensory and visual cortices (Gotgay, Giedd, Lusk et al., 2004). In adolescence, the prefrontal cortex may undergo a second ‘critical period’ of development as its connectivity is substantially refined (Lewis, 1997). Volumes of gray and white matter continue to change between childhood and young adulthood, corresponding to cognitive developments during this time (Sowell et al., 2001). There is an increase in frontal gray matter volume at the onset of puberty (age 11-years in girls and 12-years in boys) followed by a decline post-adolescence (Giedd et al., 1999). If this increase in volume truly represents a second period of overproduction of synapses, it highlights puberty as an even more important developmental period than had previously been thought (Giedd et al., 1999).

Neurotransmitter systems in the prefrontal cortex also change between childhood and young adulthood as the region undergoes the remodelling of neural connections (Rosenberg & Lewis, 1995; Spear, 2000). During adolescence the input of the excitatory neurotransmitter glutamate and inhibitory neurotransmitter GABA is reduced, whilst input of the excitatory neurotransmitter dopamine (DA) peaks during this period (Lewis, 1997). DA is the main innervator of pyramidal cells in the prefrontal cortex, cells through which all cortical output and much excitatory input is mediated (Lambe, Krimer & Goldman-Rakic, 2000). A critical shift in DA inputs to pyramidal cells in adolescence has been identified (Lewis, 1997). A key role for DA in the prefrontal cortex is in maintaining information over a
delay (Lambe et al., 2000; Lewis, 1997), i.e., in working memory (Sawaguchi, Matsumura & Kubota, 1990; Williams & Goldman-Rakic, 1995). This is achieved via the structural organisation of pyramidal cells; these cells have monosynaptic DA connections and are arranged throughout the cortex in 'stripes.' Activation, maintenance and integrity of information in working memory is achieved by the sustained firing of pyramidal neurons within 'stripe circuits' fuelled by dopaminergic input (Lewis, 1997).

Functional changes
In an fMRI study investigating the link between cognitive functions and frontal lobe maturation, adolescents (12-19 years) and young adults (22-40 years) performed two executive function tasks mediated by the prefrontal cortex: a motor timing task and a motor response-inhibition task (Rubia et al., 2000). Different regions of activation were observed between adolescents and adults during task performance. The areas recruited by adolescents were more posterior and subcortical to those recruited by adults, and were by said the authors to represent a "...functionally adequate but immature prototype system..." (Rubia et al., 2000, page 18). Moreover, the authors argued that brain changes during adolescence (e.g., myelination and reorganisation) increase cortical-subcortical connectivity and enable the transfer of functions from immature posterior/subcortical prototype systems to anterior, cortical, mature systems.

Summary of maturation of the prefrontal cortex in adolescence and adulthood
Evidence from the studies reviewed above indicates that adolescence is a key period in the development of the prefrontal cortex. Substantial reorganisation of the connectivity and neurotransmitter activity within this region occurs during adolescence, is related to puberty and continues into young adulthood. This structural reorganisation is reflected in functional imaging studies in which children and young adults recruit different brain regions whilst performing the same task. Multitasking relies on frontal lobe functioning and multitask performance is expected to continue to change into adolescence and young adulthood. Specifically, group differences in multitask performance are anticipated between adolescents and young adults.
8.1.3 The Battersea Multitask Paradigm may provide scope to assess further development

We believe the Battersea Multitask Paradigm is a suitable measure to use to investigate the ongoing development of future organisation skills in adolescents and young adults. When 10-year old children performed the paradigm (Chapter 5) they did not score near ceiling on many variables, leaving scope for further performance changes in older participant groups. Specifically 10-year olds did not score at ceiling on planning, plan following, overall performance, strategic performance, task switching and rule breaking. This was in contrast to variables on which 10-year olds achieved very high levels of performance: rule learning/ memory and recounting.

Previous studies of multitasking in children employed multitask paradigms adapted for use with children which are not directly comparable to adult tasks (Emslie et al., 2003; Martin & Kliegel, 2003; Siklos & Kerns, 2004). Although our multitask paradigm was also designed for use with children, it may be possible to use the same test to assess adults. This is because the detailed scoring system adopted in the Battersea Multitask Paradigm may be more sensitive to measuring further developmental differences in performance.

The scoring system adopted for the Battersea task is more complex than those adopted by other children’s multitask paradigms. Scoring reflects how well children remember the rules of the paradigm, how efficiently they plan their performance and how well they stick to this plan. These aspects of multitasking are not always measured in other children’s multitask paradigms. The multitask performance score of the Battersea Multitask Paradigm reflects both how well children co-ordinate performance across multiple interleaved tasks and how effectively they manoeuvre the constraints of this complex situation to their advantage, e.g., via strategic rule use. It is this aspect of the scoring system that constitutes a major departure from the scoring systems of other children’s multitask paradigms. Not only are executive co-ordination skills tested, but the successful application of these skills is also measured. In many ways this is more pertinent to multitasking in everyday life where it is important to co-ordinate performance across multiple tasks and to perform these tasks to the best of one’s ability, rendering a successful outcome.
8.1.4 Summary of introduction

The evidence we have reviewed supports the hypothesis that the processes involved in the organisation of future behaviour, and the brain regions upon which these processes are reliant, continue to develop through middle childhood, into adolescence and beyond into young adulthood. It is likely that these developments will be reflected by in the performance of adolescents and young adults on the Battersea Multitask Paradigm.
8.2 Aims and hypotheses

The aim of the present study is to test the hypothesis that the ability to organise future behaviour continues to develop through adolescence into young adulthood. We propose to achieve this by testing adolescents and young adults using the same multitask paradigm that we used to test younger children in a previous study (Chapter 5). By investigating group differences in performance between adolescents and young adults we can determine which aspects of multitasking continue to develop into adulthood. We expect performance on some but not all multitask variables to continue to develop into adulthood. Our hypotheses are summarised in Table 8.1.

Table 8.1: Predicted age group differences on multitasking variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group Differences?</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule Learn &amp; Memory</td>
<td>No</td>
<td>10-year old children were able to learn and retain the rules of the game; older participants are also expected to do equally well.</td>
</tr>
<tr>
<td>Plan</td>
<td>Yes</td>
<td>10-year olds plan at the 76% level leaving scope for further changes in planning scores. Planning skills continue to develop into adulthood: planning differences between adolescents and adults are expected.</td>
</tr>
<tr>
<td>Plan Follow</td>
<td>No</td>
<td>10-year olds were able to implement the plans they had made. Even if adolescents and adults differ in the quality of plans they make (as predicted), group differences in their ability to implement plans are not anticipated.</td>
</tr>
<tr>
<td>Multitask Performance</td>
<td>Yes</td>
<td>10-year olds scored on average 75% on multitask performance, further group differences are anticipated on the basis of the evidence supporting the continuing development of future organisation skills.</td>
</tr>
<tr>
<td>Composite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task Switching</td>
<td>Yes</td>
<td>Over 80% of 10-year olds switched efficiently between tasks, leaving some scope for further changes in task switching performance. Also, evidence supports the ongoing maturation of prospective memory, of which task switching is a fairly direct measure.</td>
</tr>
<tr>
<td>Strategic Performance</td>
<td>Yes</td>
<td>Strategic performance reflects strategic rule use. Under multitask conditions, adults are expected to use rules increasingly more strategically, due to the continued development of executive abilities sub-served by the prefrontal cortex.</td>
</tr>
<tr>
<td>Rule Breaking</td>
<td>Yes</td>
<td>30% of 10-year olds broke the rules whilst performing the multitask paradigm. We hypothesised that performance monitoring and the inhibition of rule breaking behaviour will continue to develop into adolescence and young adulthood: therefore group differences in rule breaking behaviour are anticipated.</td>
</tr>
<tr>
<td>Performance Errors</td>
<td>No</td>
<td>In previous multitask studies very few children made performance errors, no group differences are anticipated.</td>
</tr>
<tr>
<td>Recount</td>
<td>No</td>
<td>Recount was poorly designed, 10-year olds were approaching ceiling and older participants are expected to reach ceiling.</td>
</tr>
</tbody>
</table>
8.3 Method

8.3.1 Study design
This study is a cross sectional, between-groups design using independent samples. Two groups of participants were recruited to the study, a group of 14-year old adolescents and a group of young adults.

8.3.2 Ethical considerations
As outlined in previous chapters, this study was covered by ethical approval. Adolescents and their parents were provided with written information about the study and given the opportunity to ask questions in person or by telephone. Written parental consent was obtained for every adolescent who participated in the study, plus additional consent to video the test session. In addition the adolescents themselves were asked for verbal assent to participate and to be videotaped. All participants agreed to this. Adolescents received a certificate and a small prize for participating in the study (a pencil case with pencils and a ruler). The head of the school year was sent a letter of thanks and some computer vouchers as a token of appreciation. Adults received information about the study in advance, via email. On the day of their assessment they were shown the same information sheet and given a consent form to sign. Adults were provided with the opportunity to ask questions about the study by email, telephone or in person on the designated test date. Like children, adults provided written consent to participate and to have their test session videotaped. Unlike children, adults received no direct reward for their participation other than thanks, although refreshments were provided during the test session.

8.3.3 Participants
Adolescent recruitment & response rate
Adolescents were recruited from a mainstream secondary school that had existing links with the research department. As in previous studies, the Head Teacher's permission for the study was obtained first and with his endorsement letters were distributed to parents of children in two classes

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within the target year group. A three-day block of testing was agreed between the experimenter and the school during which we assessed all children who returned consent. The response rate was lower than we had hoped: only 21 children were recruited from 68 letters sent home. The aim was to recruit around 30 children, to match the target number of adult participants.

Adult recruitment & response rate

Adults were recruited from the student population and from local businesses. Local business recruits included 6 people from a management consultancy firm (mixed administrative/consultants), 2 people from an opticians' firm, 4 non-academic research staff from a local research institute and 8 people from miscellaneous white-collar occupations (e.g., environmentalist, civil servant, journalist). A further 14 participants were postgraduate university students studying unrelated basic science subjects. Initial contact was made by email. All adults who responded to the email agreed to participate, 34 respondents. On the day of testing, participants were once again provided with information about the study and informed that they could withdraw if they wished to. However, all 34 adults agreed to participate and signed a written consent form.

8.3.4 Procedure

Adolescent test environment

Test sessions were conducted in a quiet room of the school. During the session the child was seated opposite the experimenter. A camcorder fixed on a tripod stood next to the experimenter trained on the child and the test procedure was videotaped for analysis. As in previous multitask studies, the three tasks of the paradigm were laid out horizontally on the table in front of the child and the order of tasks was counterbalanced across participants.

Adult test environment

In contrast to the adolescent test environment, the adult's test environment varied considerably. Adult participants were tested in their workplace, in their homes or in testing facilities at our research institute. We ensured that all testing took place in a quiet room with a table at which the experimenter sat opposite the participant. The multitask was laid out on the table in front of the adults, in counterbalanced order, and the test session was videotaped.
Test administration
The total testing session took about 25 minutes. During this session participants performed the Battersea Multitask Paradigm followed by two sub-tests from the Weschler Intelligence Scales: vocabulary and block design.

Battersea Multitask Paradigm
The multitask paradigm we administered to adolescents and adults used identical apparatus, instructions and rules to the multitask paradigm administered to 6, 8 and 10-year old children in the first multitask study we reported (Chapter 5 and Appendix 1). Like the majority of 8 and 10-year old children in this first multitask study, adolescents and adults did not require training to learn the four rules of the game, which they learned quickly and easily. The multitask paradigm was administered using six steps that yielded six key dependent variables (learn, plan, perform, follow, recount and remember). These were scored in an identical way to the scoring system outlined in Chapter 4 (and Appendix 2).

Weschler Intelligence Scales Sub-tests
Estimates of verbal and non-verbal ability were taken for each adolescent using two sub-tests from the Weschler Intelligence Scales for Children, 3rd edition (WISC-III(UK)): vocabulary and block-design sub-tests. The same two sub-tests are found in the Weschler Adult Intelligence Scales, Revised UK Edition (WAIS-R(UK), Weschler, 1986) and adults were assessed on these tests for comparison. Raw scores on each test were transformed into standardised scores with a mean of 10 and a standard deviation of 1.5.
8.4 Results

8.4.1 Exploration of the data

Sample characteristics

55 adolescents and adults participated in this study: a 14-year old group and an adult group. There were approximately equal numbers of males and females in each age group. Distribution of ethnic diversity was broadly equal between groups: 14-years (Caucasian = 20, Asian = 1), adults (31 Caucasian = 31, Asian = 1, Chinese = 2). Sample characteristics are summarised in Table 8.2.

Table 8-2: Sample characteristics

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Age (years, months)</th>
<th>SD (months)</th>
<th>Range (months)</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-years (21)</td>
<td>14y 1m</td>
<td>3.90</td>
<td>156 - 173</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Adult (34)</td>
<td>27y 4m</td>
<td>42.85</td>
<td>265 - 446</td>
<td>12</td>
<td>17</td>
</tr>
</tbody>
</table>

Adolescents performed the vocabulary and block design sub-tests of the WISC-III\textsuperscript{UK} and adults performed the same sub-tests from adult WAIS-R\textsuperscript{UK}. Estimates of verbal and non-verbal ability are presented as scaled scores in Table 8.3.

Table 8-3: WISC-III\textsuperscript{UK} and WAIS-R\textsuperscript{UK} vocabulary and block-design scaled scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Verbal IQ Measure</th>
<th>Performance IQ Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vocabulary Test (mean scaled score = 10)</td>
<td>Block Design Test (mean scaled score = 10)</td>
</tr>
<tr>
<td>(N)</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>14-years (21)</td>
<td>7.19</td>
<td>2.85</td>
</tr>
<tr>
<td>Adult (32)*</td>
<td>11.44</td>
<td>2.91</td>
</tr>
</tbody>
</table>

*Two adult participants were psychology experimenters who were familiar with the WAIS-R\textsuperscript{UK}, they performed the multitask but not the IQ sub-tests.
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Sampling issues
The means in Table 8.3 highlight a clear sampling issue. Although 14-year olds were sampled from a mainstream Secondary School, the 21 adolescents in this sample performed below average on IQ sub-tests. Likewise, the adults in this study performed above average on these tests. Analysis of variance confirmed that these differences were significant between the groups for vocabulary \[F (1,51) = 27.44, p < .001\] and block design tests \[F (1,51) = 54.98, p < .001\].

Whilst it is difficult to draw firm conclusions on the basis of two IQ sub-tests, the purpose of assessing IQ in this study was to ensure broadly comparable groups. The adult comparison group was sampled from local businesses and the student population and there is a clear disparity between their IQ sub-test performance and that of the 14-year olds. Means were not normally distributed for either group, the 14-year old participants had a negatively skewed distribution of standard scores, and the adults demonstrated a positively skewed distribution of standard scores. It is possible that this difference between groups might influence group comparisons on key multitask variables. We will consider this issue further in the discussion section.

Parametric or non-parametric analyses?
As in previous chapters, the performance of adolescents varied more considerably than the performance of adults. Levene’s test for Homogeneity of Variance was conducted for the six key variables and was significant for the ‘multitask performance’ variable. Therefore group differences on the multitask performance variable were compared using a non-parametric Mann-Whitney U test.

8.4.2 Group comparisons on multitask variables
Figure 8.1 illustrates 14-year olds and adults scores on each of the key dependent variables of multitasking (described as percentages to allow comparisons between variables scored on different scales). The only dependent variables for which significant group differences were observed were multitask performance variables. In the section that follows, scores on each variable are discussed with respect to the hypotheses regarding group differences that we outlined previously.
[1] Rule Learning and Rule Memory

No significant differences were anticipated between 14-year olds and adults ability to learn and retain the rules of the multitask paradigm. Rule learning and memory scores are detailed in Table 8.4. One-way analysis of variance confirmed the lack of significant group differences for both rule learning \([F(1,53) = 0.77, \text{NS.}]\) and rule memory \([F(1,53) = 0.00, \text{NS.}]\).

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Rule-learning (score out of 18)</th>
<th>Rule-memory (score out of 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>14-years (21)</td>
<td>16.43, SD=0.92</td>
<td>16.24, SD=1.13</td>
</tr>
<tr>
<td>Adults (34)</td>
<td>16.67, SD=1.10</td>
<td>16.23, SD=1.35</td>
</tr>
</tbody>
</table>
[2] Planning

Contrary to expectation, no group differences were found between adolescents' and adults' planning skills. Both 14-year olds and adults scored well on the planning measure. Analysis of variance confirmed there were no significant group differences \([F (1,53) = 3.03, p > .05]\). Means and standard deviations are detailed in Table 8.5. The planning score measures whether a participant's plan includes the intention to perform all 3 tasks and to prioritise yellow items and filling clusters of items; these elements are most pertinent to successful performance. The means in Table 8.5 indicate that both adolescents and adults form plans that incorporate these elements.

Table 8-5: Planning scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Planning (score out of 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>14-years (21)</td>
<td>10.57 (1.43)</td>
</tr>
<tr>
<td>Adults (34)</td>
<td>11.32 (1.63)</td>
</tr>
</tbody>
</table>

[3] Plan Following

In line with expectation, no group differences in plan following were observed, Table 8.6. 14-year olds and adults not only formulated high quality plans, but were equally able to implement the plans they had made. One way analysis of variance indicated a trend towards significant group differences in plan following scores \([F (1, 53) = 3.91, p = .053]\). However, when group differences were also explored using analysis of co-variance, co-varying for initial planning scores, no group differences were observed \([F (1,52) = 0.83, p > .05]\).

Table 8-6: Plan following scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Plan Follow (score out of 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>14-years (21)</td>
<td>10.10 (1.44)</td>
</tr>
<tr>
<td>Adults (34)</td>
<td>10.97 (1.67)</td>
</tr>
</tbody>
</table>
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Group differences in the composite multitask performance score were predicted and found. The means in Table 8.7 indicate that 14-year olds performed less well than adults' did, an analysis of variance (ANOVA) confirmed this group difference to be significant: F (1,53) = 12.53, p = .001. Group comparisons for multitask performance scores failed Levene's test for homogeneity of variance as there was greater variability on the performance of 14-year olds than the performance of adults. A non-parametric Mann-Whitney U test was performed which also showed significant group differences in multitask performance: z = -3.04, p = .002. Given the sampling issues highlighted above, we wanted to investigate the impact IQ differences may have had on multitask performance. As ANOVA produced the same results as the non-parametric test, we performed an analysis of co-variance (ANCOVA), to investigate group differences in multitask performance whilst co-varying for scaled IQ sub-test scores. Significant group differences in performance remained after IQ differences were accounted for: F (1,52) = 8.65, p < .01.

Table 8-7: Multitask performance scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Composite Performance Score (max. = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>14-years (21)</td>
<td>16.14 (2.51)</td>
</tr>
<tr>
<td>Adults (34)</td>
<td>18.11 (1.62)</td>
</tr>
</tbody>
</table>

(a) Task switch performance

For the adolescent and adult sample, the number of task switches made ranged from 2 to 13, see Figure 8.2. The lowest score in the range is 2, indicating that every participant managed to perform all three tasks. However, recall that 2 switches is still considered an inefficient switch strategy as it demonstrates a degree of inflexibility when comparing 'point-scoring' options between tasks. Compared to the switching performance of children in previous chapters, no adolescents or adults switched between tasks numerous times and the maximum number of task switches was 13. In the present study an efficient switch strategy was defined as when the participant switched 3-to-13 times.
In line with expectation, 14-year olds were significantly poorer at switching efficiently between tasks than adults were. Switch performance is illustrated in Figure 8.3. 23.8% (N=5) of 14-year olds selected an inefficient switch strategy, in contrast to 2.9% of adults (N=1). Thus 76.2% of 14-year olds (N=16) selected an efficient switch strategy. A Chi squared analysis indicated that this difference was significant between age groups \( \chi^2 = 5.82, \text{df} = 1; p < .05 \).

Figure 8-3: Task switch score (% of participants who select inefficient and efficient switch strategies)
(b) **Strategic multitask performance**

Similarly, group differences in strategic aspects of multitask performance were observed. Strategic performance scores are also detailed in Table 8.8. 14-year olds scored significantly fewer strategic performance points than adults: $F (1,53) = 12.49$, $p = .001$. Once again the level of variation on strategic performance scores between adolescents and adults violated the assumption of homogeneity of variance upon which the parametric analysis of variance relies. A non-parametric Mann-Whitney U test confirmed significant group differences in strategic performance: $z = -2.97$, $p = .003$. We also investigated group differences in strategic performance whilst co-varying for IQ differences between the groups. Analysis of co-variance revealed that group differences in strategic performance remained significant after IQ differences were accounted for: $F (1,52) = 6.86$, $p < .01$.

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Strategic Performance (score out of 18)</th>
<th>Penalty Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Errors N Participants</td>
</tr>
<tr>
<td>14-years (21)</td>
<td>15.28 (1.73)</td>
<td>0</td>
</tr>
<tr>
<td>Adults (34)</td>
<td>16.65 (1.12)</td>
<td>0</td>
</tr>
</tbody>
</table>

(c) **Rule breaking and performance errors**

In the first multitask study (Chapter 5), over 30% of 10-year olds broke the rules of the game during performance. The number of participants in each group who broke the rules or made performance errors is detailed in Table 8.8. We hypothesised that as rule breaking is reliant upon performance monitoring and inhibitory control, adolescents would show a higher incidence of rule breaking behaviour than adults, in whom these executive skills are better developed. In fact, the opposite pattern of results was observed. Only 14% of 14-year olds broke the rules of the game compared to 32% of adults. It seems that rule breaking was just as attractive to adults as it was to younger children in our previous studies. No group differences were anticipated in the number of errors made by 14-year olds and adults, as in previous multitask studies the number of participants making any errors was very low. No participants in the present study made any performance errors.
[5] Recount
As predicted both 14-year olds and adults scored at ceiling on the recount measure, Table 8.9, and no significant group differences were observed on this measure: F(1,53) = 0.75, p > .05. Unfortunately the recount score was designed based on the spontaneous recounting of 6 and 8-year olds, as their spontaneous verbal output was limited this in turn limited the recount score. As such the scoring system failed to capture the level of reflection typically contained in adult discourses. One key difference between the recounting of adults compared to younger children and adolescents was that adults almost invariably began by telling the experimenter what they would have done differently.

Table 8-9: Recount scores

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Recount (score out of 9) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-years (21)</td>
<td>8.76 (0.76)</td>
</tr>
<tr>
<td>Adults (34)</td>
<td>8.91 (0.51)</td>
</tr>
</tbody>
</table>

[6] Additional Analyses
In order to investigate the relationship between IQ and multitask variables further, we correlated age scaled IQ scores with multitask variables for each age group. The results of these correlations are detailed in Table 8.10 for 14-year olds and Table 8.11 for adults.

Table 8-10: Correlation of IQ and multitask variables - 14-year olds

<table>
<thead>
<tr>
<th></th>
<th>Learn</th>
<th>Memory</th>
<th>Plan</th>
<th>Follow</th>
<th>Perform</th>
<th>Switch</th>
<th>Strategy</th>
<th>Penalty</th>
<th>Recount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vocab.</td>
<td>.53*</td>
<td>.05</td>
<td>.33</td>
<td>.36</td>
<td>-.02</td>
<td>-.12</td>
<td>.21</td>
<td>-.42</td>
<td>.59**</td>
</tr>
<tr>
<td>Blocks</td>
<td>.29</td>
<td>.20</td>
<td>.39</td>
<td>.21</td>
<td>-.20</td>
<td>-.33</td>
<td>.09</td>
<td>-.14</td>
<td>-.11</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01

For the 14-year olds a significant correlation was observed between verbal IQ sub-test performance and rule learning, and verbal IQ sub-test performance and recount. No significant relationships were identified between non-verbal IQ sub-test performance and multitask variables. For the adults no
significant relationship was observed between either the verbal or the non-verbal IQ sub-tests and multitask variables.

Table 8-11: Correlation of IQ and multitask variables – adults

<table>
<thead>
<tr>
<th></th>
<th>Learn</th>
<th>Memory</th>
<th>Plan</th>
<th>Follow</th>
<th>Perform</th>
<th>Switch</th>
<th>Strategy</th>
<th>Penalty</th>
<th>Recount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vocab.</td>
<td>.06</td>
<td>.17</td>
<td>.25</td>
<td>.21</td>
<td>.23</td>
<td>.34</td>
<td>.02</td>
<td>.18</td>
<td>-.03</td>
</tr>
<tr>
<td>Blocks</td>
<td>-.07</td>
<td>.04</td>
<td>.07</td>
<td>.08</td>
<td>-.17</td>
<td>.29</td>
<td>-.33</td>
<td>-.17</td>
<td>.16</td>
</tr>
</tbody>
</table>

*p < .05, ** p < .01
8.5 Discussion

This study was designed to investigate the ongoing development of the organisation of future behaviour in a sample of adolescents and young adults. Our hypothesis was that future organisation skills, as measured by multitask performance, continue to develop through adolescence into adulthood. The results support this hypothesis. Moreover, we have shown that our measure, the Battersea Multitask Paradigm, can be meaningfully administered to young adults as well as to 6 year old children. To our knowledge this is the first multitask paradigm to use an identical administration procedure with such a wide age range of participants.

8.5.1 Sampling issues

Before proceeding to discuss the findings of this study in greater detail, one caveat must be addressed. Unfortunately, the groups in this study were not matched for intellectual ability. This presents a potentially serious problem for the between group comparisons conducted in this study. We tested participants’ performance on two sub-tests from an IQ test battery in order to assess overall group comparability. Group comparability was a particular issue in this study as we were sampling adults from a variety of community settings and comparing them to children from a mainstream school. Using only two IQ sub-tests does not guarantee an accurate measure of IQ, and it is possible that had we conducted a full IQ test on all our participants the size of the discrepancy between groups would have been less. However, the pattern of negative and positive skews in our groups indicates that the samples are different to one another. This difference could be explained by socio-economic differences between our groups. Although the 14-year olds came from a mainstream school, the school was located in a slightly lower socio-economic area than the schools we had sampled from in our previous studies. In comparison, the majority of adults in this study had professional occupations, placing them in a different socio-economic group.

Accepting the presence of IQ differences in our sample, the key question becomes - does IQ have a bearing on multitask performance? One way we investigated this question was to seek group differences in multitask performance after accounting for highly significant group differences in IQ. When we co-varied for IQ, performance differences remained robust. Furthermore, we correlated IQ
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sub-test scores with multitask variables for both age groups. For 14-year olds, scores on the performance IQ sub-test did not correlate with any of the key multitask variables. Significant correlations were observed between verbal IQ sub-test performance and two multitask variables, rule learning and recount. This correlation between a measure of verbal IQ and two multitask scores suggests that 14-year olds' verbal ability did relate to performance on two aspects of multitasking (learning 4 rules and recounting what has been achieved). It is interesting to note that both multitask variables themselves tap verbal abilities, and this is likely to explain the relationship observed. However, verbal IQ did not correlate with any multitask variables for which group differences were observed. Furthermore, in adults, no significant correlations were observed between performance on either IQ sub-test and multitask variables. Another fact to consider is that the 14-year old participants did not differ from the young adults on the majority of multitask variables. If IQ differences were to have an impact they would likely have influenced many multitask variables. Finally, the group differences in multitask performance that we found had been predicted on the basis of literature supporting the ongoing development of the cognitive abilities underlying multitask performance.

The adult multitasking literature is contradictory with regards to the influence of IQ on multitask performance. At first glance, IQ and multitask proficiency appear to be unrelated. Shallice and Burgess (1991) reported frontal lobe patients with preserved IQ's in the high average range who demonstrated marked impairments in multitask performance. However, on closer examination, these patients could be shown to have deficits in 'fluid intelligence' (Duncan, Burgess & Emslie, 1995). The relationship between frontal lobe functioning and the ability to solve novel, abstract problems has been established and frontal executive skills have been equated with Spearman’s 'g' or general intelligence (Duncan et al., 1995; Duncan, Emslie, Williams et al., 1996; Duncan, Seitz, Kolodny et al., 2000). A second strand of evidence comes from the general observation that in developmental studies intellectual ability often correlates closely with emerging cognitive skills, over and above the correlation that would be expected by the simple fact of comparing two developing capacities. In this respect it is possible to predict that for adult studies, IQ measured by traditional intelligence tests such as the Weschler Intelligence Scales may not play a significant role in multitask performance, as is suggested by the single dissociation reported by Shallice and Burgess (1991). However, the picture could be different for a developmental sample where IQ may have an impact upon multitask performance as a
developing ability. That said, in our sample, IQ only correlated with two multitask variables for which we did not find developmental differences.

In sum, the analysis of co-variance and patterns of correlation we used to investigate the relationship between IQ and multitasking in our sample do not support a significant influence of IQ on multitask performance. However, IQ differences between our samples are robust and we cannot rule out the possibility that these may influence the group differences in multitasking observed in this study. In Chapter 10 we will contrast the performance of young adults to the performance of the 10 year olds in our first multitask study, whose intellectual ability is more akin to that of our adult sample. For now, we shall bear this caveat in mind as we go on to consider the results of the present study.

8.5.2 Group differences in multitasking

Group differences that were anticipated and confirmed relate to performance on the Battersea Multitask Paradigm. Adolescents and young adults performed the multitask paradigm differently from one another, with adults obtaining a better overall score, a better strategic performance score and being more likely to adopt an efficient switch strategy.

Multitask performance tests the individual’s ability to organise future actions. As such, group differences in multitasking represent the ongoing development of this complex skill into young adulthood. Our results build upon the literature outlined in the introduction where we discussed evidence to support the development of the cognitive skills underlying the organisation of future actions through adolescence into young adulthood. Specifically, prospective memory, working memory and executive functions show developmental trajectories that extend into, and in some instances beyond adolescence (e.g., Ceci & Bronfenbrenner, 1985; Gathercole et al., 2004; Anderson, 2002). In addition the protracted development of the prefrontal cortex provides a sound biological basis upon which to underpin these extended developmental trajectories. The prefrontal cortex is one of the last regions of the brain to achieve full structural and functional maturation (Fuster, 1989, Giedd et al., 1996.), and appears to undergo a significant period of consolidation and change during adolescence (Rubia et al., 2000).
Strategic aspects of multitask performance were also significantly different between adolescents and young adults. The strategic performance score measures how well participants are able to apply the rules of the multitask paradigm to their strategic advantage. Adults were able to do this extremely well scoring 92% of available points and 14-year olds also scored well on this measure obtaining an average of 85% of possible points. Contrasting these results to the strategic performance scores of 6, 8 and 10-year old children in our earlier studies, 6-year old children obtained just 50% of strategic performance points, 8-year olds 60% and 10-year-olds 75%. Recall that when performing the tasks individually in the single task study (Chapter 7), 6 and 8-year old children still only managed to achieve 75% of strategic performance points. This indicates that strategic rule use itself develops further into adolescence and young adulthood as gains in scores were observed. It is likely that this reflects developments in strategy use which continue to mature throughout childhood and adolescence into young adulthood (Anderson et al., 2001b; De Luca et al., 2003; Levin et al., 1991).

As predicted, task switch scores were significantly different between the adolescents and adults in this study. 14-year old participants were significantly less efficient at switching between tasks than were adults: 25% failed to switch efficiently between tasks. In fact, 14-year old participants scored at a similar level to the 10-year old children in our previous multitask study (Chapter 5), 20% of whom adopted an inefficient switch strategy. In contrast to these younger participants, only one adult failed to adopt an efficient switch strategy, clearly marking the adults performance from that of adolescents and younger children. Task switching relies upon prospective memory skills and this result indicates that prospective memory develops further between late childhood/ adolescence and young adulthood.

Considering strategic performance and task switch scores together gives an interesting indication of what is likely to develop between adolescence and young adulthood. Fewer 10 and 14-year olds adopt an efficient task-switching strategy than young adults, therefore this ability appears to develop further between late childhood and young adulthood. This finding is concordant with the research literature. Although the general ability to flexibly switch between tasks is fairly well developed by age 10-12 years, the ability to successfully apply this switching across multiple dimensions continues to develop into adolescence (Anderson, 2002.). As discussed above, adolescents and young adults also differ on strategic aspects of multitask performance. Strategic problem solving skills show steady increments
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from middle childhood through adolescence into young adulthood (Anderson, 2002; Anderson et al., 2001b; Levin et al., 1991). The evidence suggests different developmental trajectories for these two aspects of multitask performance. We shall return to this issue in Chapter 10 when we examine developmental trajectories in more detail.

The scoring system we have adopted in the Battersea Multitask Paradigm appears to provide a more sensitive index of developmental differences than that of other multitask paradigms designed for children. For example, it enables us to ask questions about the relative influences on strategy versus mental flexibility upon multitask performance. The task set up and scoring system of the HEXE children’s multitask paradigm focuses on task switching and as a result the performance of older children is close to ceiling (Martin & Kliegel, 2003). The Six Parts Test was designed to capture an element of strategic performance and scores on this test show steady improvements in children up to age 16-years (Emslie, 2004), complementing the results reported here. Unlike the Battersea Multitask Paradigm both these tests are not suitable for use with young adults. The Battersea Multitask Paradigm captures not only how well children co-ordinate their multitask performance, but also how efficiently they perform the individual tasks set out in front of them. We believe it is this level of complexity that enables the Battersea Multitask Paradigm to effectively become a life span task.

We had predicted significant differences between adolescents and young adults planning scores, this hypothesis was based upon literature that supports the ongoing maturation of planning skills into young adulthood (Anderson, 1998; Klahr et al., 1993; Levin et al., 1991). However, contrary to expectation, group differences in planning were not found. Both adolescents and adults were very good planners, forming plans that were awarded around 90% of available points. Furthermore, plan following scores indicated that adolescents and young adults were equally able to implement the plans they had formed. What might explain this result? Burgess believes that adults’ plans may even appear impoverished next to those of younger participants, as adults plan so automatically that they fail to explicate the obvious (Burgess, personal communication).

A further question arises from this finding: if adults and adolescents are equally able to form and implement a strategic plan, why do they perform the multitask differently? As discussed earlier, we
believe group differences in multitask performance represent developments in the ability to organise future behaviour. There are two further explanations as to why adolescents and adults form equivalent plans but perform differently. First, it is possible that the planning score, unlike the performance score, does not capture the complexity of adult behaviour. Adults employ more sophisticated strategies to achieve maximal performance and are able to switch fluently between multiple interleaved tasks, weighing up which parts of each task to perform to score most points. The planning scoring system we devised measures participants' intention to prioritise yellow items and filling items, and it records the number of tasks they plan to apply these rules to. However, the subtleties of weighing one task against another are not captured in the planning score as they are in the performance score. Adults may score highly on more sophisticated planning measure, although recall that Burgess believes adult plans are frequently left unspoken (Burgess, personal communication).

Second, multitask performance is not just about implementing a pre-formed plan. A flexible system of action control will be able to incorporate feedback and change activities accordingly. The Supervisory Attention System provides the opportunity to respond to and update plans and actions on the basis of feedback from monitoring the ongoing situation (Shallice & Burgess, 1996). In our multitask paradigm, it is clear that young children use self-generated feedback from monitoring their own performance much less effectively than older participants. For example, a younger child is more likely to begin filling a large pot of beads and to continue filling it up, despite being obviously worried about how long this activity is taking them. In contrast, adults who begin to fill a large pot typically realise their mistake and correct their performance on the basis of this feedback. Therefore it is possible that adults are more able to respond to self-generated feedback than adolescents are. Developmental differences in responding to feedback are not only confined to comparisons between adults and younger children. Recall that 8-year old children in our multitask training study (Chapter 6) effectively out-performed their plans and one possible explanation for this was that they were better at responding to online feedback than 6-year olds.

The finding that 30% of adults broke the rules of the multitask paradigm (specifically the pick up items one-by-one rule) was not one we had anticipated. Rule breaking was designed to be attractive to
participants and we had hypothesised that adolescents would break the rules more than adults would, however this was not the case.

Rule breaking is likely to be dependent on performance monitoring and inhibition. Inhibitory control is relatively well developed by age 10 years (Anderson, 2002; Levin et al., 1991) and this might go some way towards explaining the surprising pattern of rule breaking behaviour in adults, which resembles that of the 10-year olds in our previous study (Chapter 5). However, an inhibition account to explain rule breaking may be more relevant for younger children than for adults as we observed a qualitative difference between the rule breaking behaviour of adults and younger children. Younger children appeared to be aware of their rule breaking, frequently glancing at the examiner each time they broke the one-by-one rule. In contrast, adults showed little awareness when they broke the one-by-one rule and their rule breaking may resemble a type of performance error. Therefore performance monitoring, as measured by rule breaks, may still present a challenge to adult participants. The recount measure also taps performance monitoring skills. No group differences on this measure were anticipated or found, primarily due to ceiling effects. The recount measure was designed too simply and ought to be re-conceptualised in future versions of our multitask.

Finally, we did not predict group differences in the ability of adolescents and adults to learn and remember the rules of the multitask paradigm. This prediction was made primarily on the basis of the performance of 10-year olds in our previous multitask study, who were able to learn and retain four simple rules governing multitask performance. As anticipated, this did not present difficulties for adolescents or young adults in the present study who scored an average of 90% for rule learning and remembering.
8.6 Summary of limitations and recommendations for future studies

Unfortunately, our adolescent and adults samples were not comparable on two brief measures of IQ. An examination of the distribution of means showed that the 14-year old group had IQ scores negatively skewed below the population mean, and the adult group had IQ scores positively skewed above the population mean. This limits the validity of further comparisons between these two groups.

To address this issue we co-varied for the effects of IQ when examining group differences on multitask performance variables and found that predicted performance differences remained significant. Further, although IQ scores correlated with some multitask variables in the 14-year old group, these were not variables on which group differences were observed. That said, in future it would be advisable to investigate multitask performance of adolescents and young adults whose IQ scores are comparable. This could be combined with a study investigating multitasking skills in relation to pubertal status following the work of Davies and Rose (1999). Groups of pre-pubertal children, mid-pubertal Adolescents and post-pubertal young adults could be assessed.

Adolescents and adults scored at ceiling on the recount measure. We had designed this measure too simply. In future we could adopt a system for probing and scoring recount information based upon the recount measure of Greenwich Multitask Test in which participants’ responses to a number of questions are scored (Burgess et al., 2000).

Finally, we have tested children aged 6 years and young adults using an identical multitask paradigm. This is the first multitask paradigm to have been designed which is suitable for use across such a broad range of ages, a life-span paradigm. In Chapter 10 we investigate developmental trajectories of multitasking, drawing together data from the various studies we have conducted using the Battersea Multitask Paradigm.
8.7 Chapter summary

The results of the present study support our hypothesis that the ability to organise future behaviour continues to develop through adolescence and into young adulthood. Predicted group differences in multitask performance scores were identified and developments in strategy use and prospective memory are likely to underlie these performance differences. We have shown that our paradigm can be used to test adults as well as young children, consequently the Battersea Multitask Paradigm can be considered to be a life span multitask test, the first of its kind.
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Multitasking in autism spectrum disorder

“I bet he’ll become a rocket scientist, but I’ll probably have to dress him and drive him to work.”

(Mother speaking of her son with high functioning autism, cited in Ozonoff, Dawson & McPartland, 2002, page 18)

This mother’s comment accurately summarises the paradox faced by many children with high functioning autism spectrum disorder (HF-ASD). By definition, children with high functioning autism have normal or above normal intelligence and relatively well developed structural language and cognitive skills (Ozonoff et al., 2002). However, even though these children may go on to achieve important milestones such as forming a career or getting a university degree, they continue to have difficulties with the demands of everyday life and many struggle to live independently as adults (Howlin & Goode, 1998). One of the reasons that individuals with HF-ASD find it hard to live independently is because of their difficulties organising and co-ordinating everyday activities. Multitasking is a valid test of the everyday organisation of behaviour and it seems reasonable to believe that children with HF-ASD will demonstrate impaired multitask performance. Our multitask paradigm enables us to investigate which aspects of multitasking present difficulties for children with HF-ASD, and to form hypotheses about which underlying cognitive systems may be impaired in these children.
9.1 Introduction

The aim of this study is to investigate the organisation of future behaviour in children diagnosed with HF-ASD by evaluating their performance on the Battersea Multitask Paradigm. We begin by defining autism spectrum disorder (ASD) and identifying the sorts of everyday organisation difficulties that are associated with this disorder. We then consider the cognitive profile of executive dysfunction in ASD and discuss everyday organisation difficulties in relation to this profile. Finally the neural correlates of executive dysfunction in ASD will be outlined, following which we consider multitasking in ASD.

9.1.1 What is autism spectrum disorder (ASD)?

Autism is a developmental disorder primarily characterised by deficits in social understanding and communication. It is typically diagnosed at around 3-4 years of age, and its onset can usually be retrospectively documented to age 18-24 months (Charman & Baird, 2002). The level of social communicative impairment can vary between children, which has led to the concept of an autistic spectrum encompassing a number of disorders of varying severity. Autism spectrum disorders (ASD) can be diagnosed via one of two similar but separate classification systems, the International Classification of Diseases version 10 (ICD-10, World Health Organisation, 1993) or the Diagnostic and Statistical Manual, version IV (DSM-IV, American Psychiatric Association, 1994). Both include a category for individuals who meet full diagnostic criteria for autism, which requires a triad of impairments in communication, reciprocal social interaction and stereotyped or repetitive behaviours. In addition both classification systems include diagnostic categories for disorders related to autism but where individuals do not show the full criteria necessary for a diagnosis of autism. These include Asperger syndrome, atypical autism and pervasive developmental disorder not otherwise specified. At one end of the spectrum, individuals may be very low functioning with severe learning disabilities and little or no language ability. At the opposite end of the spectrum, children diagnosed with high functioning autism and Asperger syndrome have an IQ in the normal range but still demonstrate social understanding impairments (the key difference between these diagnoses is that children with Asperger syndrome do not have the early language delays characteristic of autism). Epidemiological studies vary in their estimations of the prevalence of autism spectrum disorders, although recent studies converge on a prevalence rate of 6 per 1,000 head of population (see Charman, 2002, for a review).
There is a higher incidence of autism spectrum disorders in boys than in girls, with estimates being approximately 4:1 across the whole autistic spectrum (Volkmar, Lord, Bailey, Schultz & Klin, 2004) rising to 10:1 at the high functioning end of the spectrum (Wing & Potter, 2002). There is growing evidence to support the biological basis of autism spectrum disorders; changes in the brain structure and function of individuals with ASD are well documented and studies are increasingly identifying genetic influences on autism (see Volkmar et al., 2004, for a recent review). In sum, the autism spectrum disorders represent a range of social communication disorders of varying severity. In this study we focus on children with a diagnosis of high functioning autism or Asperger syndrome, whom we group together under the general heading of High Functioning Autism Spectrum Disorder (HF-ASD).

9.1.2 Everyday organisation difficulties in ASD

Children with HF-ASD are commonly reported to have difficulty organising themselves to perform everyday activities. Difficulties include time management, organising the materials necessary to perform an activity and sequencing of activities; generally reflecting a deficit in the ability to plan ahead (Ozonoff et al., 2002). This has a real impact upon day-to-day life, at school children fall behind in class due to poor time management and difficulties organising their workload, and homework is all too often left at school instead of being brought home. At home activities of daily living such as getting dressed or getting ready for bed take longer to perform, often leading to frustration on all sides. Techniques to facilitate these problems include the use of regular routines and highly visible event schedules, which help the child to prepare and structure day-to-day activities (Ozonoff, 1998). At school, homework diaries are commonly used as a prospective memory aid for children, and to enable parents and teachers to keep track of homework that needs to be done. At home routines effectively help a child to ‘predict the future’ (Ozonoff et al., 2002). Research with young typically developing children finds that routines scaffold the development of future-oriented processes, as it is within the structure of a routine that a child learns to anticipate and plan (Benson, 1994; Hudson & Fivush, 1991). Sometimes sequencing events in a routine is difficult: "...although each step of the routine, such as brushing his teeth and putting on his pyjamas, in itself was not difficult for Michael, sequencing the steps and completing them independently was quite challenging for him" (Ozonoff et al., 2002, page 137). This extract is reminiscent of the event sequencing difficulties experienced by patients with...
frontal lobe damage, whose have problems combining and sequencing the steps necessary to prepare a meal (Penfield & Evans, 1935) or to go shopping (Shallice & Burgess, 1991). These real life challenges are reflected in the cognitive profile associated with autism, which is discussed below.

9.1.3 Executive function deficits in ASD

Deficits in executive functions (EF) have been the focus of investigation in a number of developmental disorders over recent years (see Pennington & Ozonoff, 1996, for a review). Executive dysfunction has been consistently observed in studies of individuals with autism, across all levels of the autistic spectrum (Pennington & Ozonoff, 1996; Ozonoff, 1998). The executive profile of children with ASD is one of 'high level' difficulties (Hughes, 2001). Deficits in cognitive flexibility and planning have been observed in most studies (Geurts, Verte & Oosterlaan, 2004; Pennington & Ozonoff, 1996), in contrast to relatively spared but not intact inhibitory functions (Geurts et al., 2004). However, the picture is somewhat less clear with regard to other executive functions such as working memory.

Card sort tasks such as the Wisconsin Card Sort Test (WCST) test cognitive flexibility by requiring the participant to shift set, the main variable of interest being the number of perseverative responses made (i.e. where a participant continues to sort by a previously correct rule despite negative feedback). Children with ASD typically demonstrate impaired performance on the WCST, making a high number of perseverative errors (Bennetto, Pennington & Rodgers, 1996; Ozonoff, Pennington & Rogers, 1991; Ozonoff & McEvoy, 1994; Ozonoff, Strayer, McMahon et al., 1994; Prior & Hoffman, 1990; Rumsey, 1985; Szatmari, Tuff, Finlayson et al., 1990). Children with ASD even demonstrate impaired performance on the WCST relative to clinical control groups of children diagnosed with learning disability, attention deficit hyperactivity disorder (ADHD) or conduct disorder (Ozonoff et al. 1991; Szatmari et al., 1990). Prior & Hoffmann (1990) used a modified version of the WCST to test participants with ASD, in which they removed all ambiguity from the rules governing card sorting performance and explicitly told participants when to change set. Despite this simplification of the test, participants with ASD were still markedly impaired relative to typically developing controls. Two studies failed to demonstrate impaired performance on the WCST in individuals with ASD. However in one participants who perseverated were dropped from further analyses making it difficult to compare to the studies mentioned above (Schneider & Asarnow, 1987). In the other, although participants with ASD
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failed to demonstrate impaired performance on the WCST, they did display set shifting difficulties on a different sorting task (Minshew, Goldstein, Muenz et al., 1992). The WCST is a complex test and there is disagreement about what it really measures (Pennington & Ozonoff, 1996). More recent investigations of cognitive flexibility in ASD have adopted different measures, including a computerised intra-dimensional/extra-dimensional set shifting task (Hughes, Russell & Robbins, 1994; Ozonoff, Cook, Coon et al., 2004) and a computerised Go-NoGo task (Ozonoff et al., 1994). These studies demonstrate that compared to typically developing controls, participants with ASD have impaired cognitive flexibility, engage in highly perseverative and inflexible strategies (Hughes et al., 1994; Ozonoff et al., 2004), and show impaired performance when shifting response set (Ozonoff et al., 1994).

Planning deficits have been consistently reported in studies of individuals with ASD (Bennetto et al., 1996; Hughes et al., 1994; Ozonoff et al., 1991, 2004; Ozonoff & McEvoy, 1994). Planning is typically assessed using tower tasks such as the Tower of Hanoi (TOH) or the Tower of London (TOL), as successful performance on these tasks requires participants to plan several moves ahead. Children with ASD planned poorly on the TOH task relative to clinical controls (Ozonoff et al., 1991; replicated by Ozonoff & McEvoy, 1994) and these planning deficits proved highly discriminatory, correctly classifying 80% of participants into ASD and clinical control groups (Ozonoff et al., 1991). Similarly, children with ASD exhibit significant planning deficits on a computerised version of the TOL compared to both clinical and typically developing controls (Hughes et al., 1994; Ozonoff et al., 2004). Prior and Hoffmann (1990) also assessed performance on a maze solving test and found planning deficits in their participants diagnosed with ASD.

Studies investigating working memory in ASD have engendered mixed results. Bennetto and colleagues (1996) investigated the performance of children diagnosed with ASD compared to age and IQ matched learning disabled controls on a variety of memory tests. Results supported significant group differences in working memory sentence span and counting span tasks, but not on tests of rote short term memory or verbal long term and recognition memory. In addition, participants with ASD demonstrated impaired performance on a temporal order judgement task relative to the learning disabled control group. However, a recent study has failed to detect group differences between
participants with ASD and clinical and typically developing controls on a test of spatial working memory, the self-ordered pointing test (Geurts et al., 2004). It has been suggested that working memory deficits in ASD may be non-spatial, and that performance on tests of spatial WM may be relatively spared due to the often superior spatial abilities of individuals with ASD (Happe & Frith, 1996; Hughes, 2001). Alternatively, it may be that impaired performance is observed in tests that tap the central executive component of working memory but not the phonological loop or visual spatial sketchpad components (Russell, Jarrold & Henry, 1994). Finally, the age at which children are assessed is important when investigating deficits in working memory and other executive impairments, as these may not be apparent until later in development after the pre-school years (Griffith, Pennington, Wehner et al., 1999).

Early studies investigating executive functions in ASD found little evidence of impaired performance on a test of inhibitory control, the Stroop colour word test (e.g., Bryson, 1983; Eskes, Bryson & McCormick, 1990). Subsequent investigations using this measure support this early finding (Ozonoff, 1997; Ozonoff & Jensen, 1999). While the original Stroop test was designed for adults (Stroop, 1935), a version has been designed specifically for children, the Day Night test (Gerstadt, Hong & Diamond, 1994). Children with ASD do not demonstrate impaired performance on this test relative to controls (Russell Jarrold & Hood, 1999).

Summing up their comprehensive review of executive functions in several developmental disorders, Pennington and Ozonoff (1996) suggested that the profile of executive dysfunction in ASD may be one of markedly impaired flexibility and planning versus relatively spared inhibition. They contrasted this cognitive profile with the executive difficulties characteristically faced by children with ADHD, who show prominent deficits in inhibitory control. This hypothesis led to three studies which have investigated the profile of executive functions across several developmental disorders. These studies were designed to address the so called ‘discriminant validity’ question: how can executive functions play an important role in any one developmental disorder when executive dysfunction has been identified in several developmental disorders? The solution to this question may lie in identifying different patterns of executive dysfunction across different developmental disorders.
Ozonoff and Jensen (1999) assessed executive profiles in three developmental disorders: ASD, ADHD and Tourette’s Syndrome (TS). Three domains of executive function were investigated: planning (Tower of Hanoi), cognitive flexibility (WCST) and inhibition (Stroop). Results supported a double dissociation between the ASD group, who demonstrated impaired performance on the TOH and the WCST but spared performance on the Stroop (relative to the other two clinical groups and controls), and the ADHD group, who demonstrated impaired performance on the Stroop test only (relative to controls). The TS group did not demonstrate deficits in comparison with any other groups. Nyden, Gillberg, Hjelmquist and colleagues (1999) compared the performance of boys with a diagnosis of Asperger’s Syndrome to that of boys with ADHD, reading and writing disorder and typically developing controls. They failed to find a consistent pattern of results for any of the groups they investigated. In their study boys with ADHD showed deficits in cognitive flexibility measured on the WCST relative to all other groups, the opposite pattern to what might be anticipated on the basis of the results reviewed above. Inhibition was assessed using the Go-NoGo test and boys in all three clinical groups demonstrated impaired performance (slower reaction times) relative to controls, rendering results from this test non-specific to any one disorder. Geurts and colleagues (2004) assessed performance across five domains of executive function: inhibition, visual working memory, planning, cognitive flexibility and verbal fluency. They compared well-characterised groups of children with ADHD, high functioning autism (HF-ASD) and typically developing controls (TD). They found that in general participants with HF-ASD displayed more severe executive deficits across a range of executive domains. Children with HF-ASD demonstrated impaired performance on tests of planning and cognitive flexibility relative to ADHD and TD controls. Both ADHD and HF-ASD children were impaired relative to TD controls on tests of inhibitory control and verbal fluency. Children with ADHD did not perform more poorly than children with HF-ASD on any of the measures, evidence against the double dissociation reported by Ozonoff and Jensen (1999).

Summarising the evidence reviewed above, we can draw some conclusions about the profile of executive functions in ASD. Executive deficits in ASD are typically more pronounced than those observed in other developmental disorders (Pennington & Ozonoff, 1996) and may occur across a range of domains of executive function (Geurts et al., 2004). Planning and cognitive flexibility stand out as areas of executive function that present particular difficulties for individuals with ASD (Geurts et al., 2004).
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2004; Hill, 2004; Ozonoff et al., 2004; Ozonoff & Jensen, 1999), in comparison to inhibition which is less impaired, although not unimpaired (Geurts et al., 2004; Nyden et al., 1999; Ozonoff et al., 1994). There is less consensus over working memory impairments in ASD, which may be domain specific (Hughes, 2001). The temporal ordering of information appears to present problems for individuals with ASD, although this research needs to be replicated (Bennetto et al., 1996). Further research using more specified tests will be necessary before executive function profiles can be used to effectively discriminate between developmental disorders, although this line of inquiry does hold promise (Geurts et al., 2004).

9.1.4 Behavioural correlates of executive dysfunction in ASD

Although it is probable that this profile of executive dysfunction has a significant impact upon the everyday lives of children with HF-ASD and their families, few studies have sought to measure this effect. Executive dysfunction in children and adults with HF-ASD correlates significantly with measures of adaptive behaviour (Ozonoff et al., 2004). Joseph and Tager-Flusberg (2004) looked for relationships between executive functions and the triad of core symptoms in autism and found that performance on a high level test of executive function (the Tower of London) was related to communication symptoms in school age children with autism, whilst inhibition (Day/Night Stroop) and working memory (span) task performance were not. Executive function performance was not related to repetitive behaviour symptoms or reciprocal social interaction (Joseph & Tager-Flusberg, 2004). However, other researchers have suggested that poor cognitive flexibility may be related to the everyday repetitive behaviours that characterise ASD (Hughes, 2001), and can be seen in autistic individual’s preference for routine and resistance to change. Deficits on tasks tapping the ventromedial prefrontal cortex correlate with performance on tests of joint attention, a crucial early form of social interaction (Dawson, Munson, Estes et al., 2002). It is likely that an impaired ability to make judgements about the temporal order of events can lead to children getting muddled following the steps to a goal, like the child described earlier who needed help to order the steps of his bedtime routine.

A measure has recently been designed to bridge this gap between cognitive test performance and everyday abilities. The Behaviour Rating Inventory of Executive Function (BRIEF) is a parent and teacher questionnaire designed to assess executive function behaviours in everyday environments.
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(Gioia, Isquith, Guy et al., 2000). The questionnaire consists of 86 items divided into 8 sub scales, each representing a different aspect of executive functioning: inhibit, shift, emotional control, initiate, working memory, plan/ organise, organisation of materials and monitor (see Appendix 5 for details). The sub scales in turn contribute to 3 broader index scales. A 'behaviour regulation index' represents the child's ability to use inhibition to regulate behaviour, including emotional behaviour and the ability to change set. A 'metacognition index' is an index of higher cognitive functions such as planning, organising, initiating and problem solving, which are all constrained by the limits of working memory. These two index scores are effectively hierarchical, in that behavioural regulation is likely to be a precursor to metacognitive control (Gioia et al., 2000). Finally, a 'global executive composite' gives an overall summary score of executive ability.

The BRIEF has been used with several clinical groups and a BRIEF profile for a mixed group of children with autism spectrum disorders has been established. This group comprised 40 children (31 boys, 9 girls), of whom 10 were diagnosed with HF-ASD, 17 with Asperger's and 13 with PDD not otherwise specified. The group had above average intellectual ability. Their parent and teacher scores on the BRIEF were compared to those of an age and social economic status matched control group of 26 children (17 boys, 9 girls). The clinical group scored significantly more highly than the controls on all eight sub-scales and all three index scores (a higher score represents greater difficulties), indicating that relative to controls children with ASD exhibited deficits in all aspects of executive functioning, despite having above average intellectual ability. In a further study the same researchers examined BRIEF profiles within and between several developmental disorders (Gioia, Isquith, Kenworthy & Barton, 2002). Results indicated that children with ASD and ADHD scored more highly on all sub scales compared to children with traumatic brain injury (TBI) or reading disabilities. The ADHD group was recognisable for having greater deficits on the inhibition sub scale compared to other sub scales. The ASD group could be distinguished by highly elevated scores on the shift scale, which measures cognitive flexibility, alongside elevated scores on all other sub scales. In sum, the BRIEF profile of children diagnosed with HF-ASD is one of significant difficulties across multiple dimensions of executive functioning, with particular difficulties in flexibility (scored on the shift sub scale). Overall this profile is congruent with the experimental executive function literature discussed earlier, which support
a pattern of significant impairments on tests reliant on a variety of executive functions, with particular
deficits observed in those tapping cognitive flexibility and planning.

9.1.5 Neural correlates of executive dysfunction in ASD

Executive functions are associated with the frontal lobes of the brain and adults with frontal lobe
damage exhibit executive dysfunction (e.g., Tranel, Anderson & Benton, 1994.). The frontal lobes are
extensively connected to other regions of the brain, and hence are well placed to co-ordinate and
sequence the activity of other brain regions (Fuster, 1998, 2001; Stuss & Benson, 1987). Observations
that the cognitive and behavioural impairments found in autism resemble those of adult patients with
frontal lobe injuries led to the hypothesis that frontal lobe damage plays a causal role in autism (e.g.,
Damasio & Maurer, 1978; Rogers & Pennington, 1991; Pennington & Ozonoff, 1996). There is
evidence to support atypical structural and functional frontal lobe development in autism (see Volkmar
et al., 2004 for a review). Maturation of the frontal cortex may be delayed in autism (Zilbovicius,
Garreau, Samson et al., 1995). Increased white matter in the whole brain has been reported in infants
and toddlers with autism (Courchesne, Carper & Akshoomoff, 2003; Courchesne, Kams, Davis et al.,
2001) and it has been suggested that this reduces overall functional integration and connectivity
(Horowitz, Rumsey, Grady et al., 1988). Reduced dopaminergic activity (Ernst, Zametkin, Matoshi et
al., 1997) and increased levels of serotonin (Chugani, Muzik, Rothermel et al., 1997) have also been
reported in the prefrontal cortex of individuals with autism. The dorsomedial prefrontal cortex may be
critical for social cognition, and its disruption may lead to the social impairments observed in autism
(Schultz, Grelotti, Klin et al., 2003). Likewise the ventromedial prefrontal cortex forms part of the brain
system specialised in social processing (Stone, Baron-Cohen & Knight, 1998). Specifically this region
has been shown to play an important role in ‘emotional learning’ in terms of forming stimulus-reward
associations (Rolls, 1990). Children with autism perform poorly on tasks known to tap this region of the
brain (Dawson, Meltzoff, Osterling et al., 1998) and performance on these tasks correlates highly with
performance on tests of joint attention, a crucial early form of social interaction (Dawson et al., 2002).
The dorsolateral prefrontal cortex (DLPFC) has been most closely linked to executive functions
involved in the organisation of future actions (Burgess et al., 2000; Glisky, 1996); reduced activation in
this region has been reported when individuals with autism perform working memory tasks known to be
dependent upon the DLPFC (Luna, Minshew, Garver et al., 2002).
The frontal lobes are not the only region of the brain to be implicated in autism. The amygdala and limbic system circuitry are also of significant interest, given their role in social emotion processing (LeDoux, 1996). Abnormalities in the structure and function of this region have been found (e.g., Castelli, Frith, Happe et al., 2002). Recently attention has turned to the fusiform face area on the lateral aspect of the fusiform gyrus. It has been shown that this area is involved in face recognition and is hypoactive in autism (e.g., Schultz, Gauthier, Klin et al, 2000). Furthermore, the posterior region of the superior temporal sulcus (STS) is involved in perceiving dynamic social signals, such as direction of eye gaze (Schultz et al, 2003). This promising region is currently under investigation.

9.1.6 Multitasking in ASD

To the best of our knowledge, only one study has investigated multitasking in autism spectrum disorder. This was done as part of the validation of the Behavioural Assessment of the Dysexecutive Syndrome (BADS-C, Emslie et al., 2003). A group of children who had been referred for clinical assessment performed all sub tests of the BADS-C including the Six Parts multitask test. The group consisted of 38 children with ADHD, 5 with Attention Deficit Disorder (ADD), 13 with ASD, 3 with traumatic brain injury (TBI), 2 with developmental co-ordination disorder (DCD) and 7 with dyslexia. They were compared to children who were participating in follow-up studies but had not been referred for clinical assessment. This comparison group consisted of 10 children with congenital adrenal hypoplasia (CAH), 13 with diabetic hypoglycaemia and 23 with TBI. In addition performance was compared to 259 typically developing control children. Results supported deficits in performance on the Six Parts multitask test in children with ASD, ADHD and clinically referred TBI children, relative to all other clinical groups and controls. This result suggests that multitasking performance may be impaired in at least two developmental disorders and in childhood acquired brain injury.

Three studies report multitasking deficits in children and adolescents with ADHD, although the reasons for deficient performance are different between studies (Clark, Prior & Kinsella, 2000; Kliegel & Kerber, in prep.; Siklos & Kerns, 2004). Clark and colleagues (2000) used a modified version of the Six Elements Test (Shallice & Burgess, 1991) to investigate multitasking deficits in adolescents with ADHD relative to adolescents with other clinical diagnoses (oppositional defiant disorder, ODD; conduct disorder, CD) and community controls. Adolescents with ADHD performed fewer tasks than
adolescents in either control group and did not break the rules governing task performance, which the authors attributed to an impaired ability to strategically plan and organise information and to monitor ongoing performance (Clark et al., 2000). Siklos and Kerns (2004) recently replicated this result with a group of younger children with ADHD who performed a children's multitask paradigm based on the Six Elements Test (the Children's Six Elements Test, C-SET). Seven to 15-year old children with ADHD performed fewer tasks compared to a typically developing matched control group but did not break the rules of the test. In both these studies individuals with ADHD performed fewer tasks than controls. However, Kliegel & Kerber (in prep.) found that children with ADHD performed just as many tasks as typically developing controls on their computerised HEXE multitask paradigm, also an adaptation of the Six Elements Test (Kliegel & Martin, 2000). Like the children and adolescents in the previous two studies the children with ADHD in Kliegel and Kerber's study did not break the rules governing task performance significantly more than controls. However, they did make significantly more performance errors than controls. Thus, performing as many tasks as controls appears to have been at the expense of accurate performance, indicative of a trade-off in attentional resources (Kliegel & Kerber, in prep.).

In sum, these studies suggest that children with ASD and children with ADHD have multitasking deficits, although the exact nature of these deficits remains unclear.

Prospective memory has been investigated in one study of children with ASD, although the focus of this investigation was not prospective memory per se but metacognition (Farrant, Boucher & Blades, 1999). In this study metacognitive abilities in children with ASD were assessed via a series of metamemory tasks, two of which were prospective memory tasks. Metacognition is defined as 'one's knowledge of one's own thought processes' and includes the ability to monitor the state of one's cognitive system (e.g., know that an item has been memorised) and to use this information to direct behaviour (Wellman, 1985; cited in Farrant et al., 1999). It has been suggested that metacognition is impaired in autism (Baron-Cohen, 1989; Hobson, 1993). Metacognitive skills are hypothesised to play a role in prospective remembering, as successful prospective remembering is likely to rely upon knowledge of one's own memory processes. For example, remembering to take medication may rely upon placing the medication in view, setting an alarm etc. Farrant et al. (1999) hypothesised that owing to metacognitive deficits children with ASD would be impaired in their ability to explicate their own memory strategies, and that this impairment would be greater for prospective than retrospective
strategies as prospective memory involves greater metacognitive demands. Metacognitive skills in participants with ASD, children with learning difficulties and typically developing controls were assessed using two verbal prospective memory tasks involving planning ahead, and one verbal retrospective memory task involving retracing steps. Participants were asked two prospective memory questions. One tested children's ability to prepare to recall an object at a later time ("what if you were going swimming with the school tomorrow and you wanted to be sure to remember to bring your swimming things to school?"). The other tested children's ability to prepare to recall an event at a later point in time ("what if you were invited to go to a friend's birthday party next week, how could you make sure you remembered his party?"). The retrospective memory question tested children's ability to recall where an object had been lost ("what if you lost your coat while you were at school, how would you try to find it?"). The results of the study failed to demonstrate significant metamemory deficits in children with ASD relative to either control group for both prospective and retrospective memory, indicating that children with ASD have access to knowledge about the strategies they use to aid their prospective and retrospective remembering. There was a qualitative difference in the types of memory strategy that the children with ASD suggested; they preferred to use themselves or objects as prospective cues rather than using other people to remind them of something, whereas controls showed no such preference. In the Battersea Multitask Paradigm the recount measure is most likely to rely on metacognitive ability, as it assesses how well a child has monitored the outcome and success of their own performance. On the basis of research theorising that children with ASD do have metacognitive difficulties we might anticipate scores on the recount measure to be impaired in children with ASD relative to controls (Baron-Cohen, 1989; Hobson, 1993). However, the results of Farrant and colleagues' study suggests that children with ASD have similar access to the prospective memory strategies they adopt, hence recount scores would be similar across ASD and control groups.

**9.1.7 Section summary**

Children with ASD have difficulty organising their everyday activities and typically need a lot of support to do this effectively (Ozonoff et al., 2002). The cognitive profile of ASD indicates some executive function deficits, particularly in planning and cognitive flexibility (Geurts et al., 2004; Ozonoff & Jensen, 1999). This profile of executive dysfunction impacts upon day-to-day behaviour (Gioia et al., 2000,
Executive dysfunction in autism has been related to abnormalities in the structure and function of the frontal lobes (Volkmar et al., 2004).

Multitasking is a good methodology to use to investigate everyday organisational difficulties in children with ASD. Multitasking is a test of everyday organisational skills with high ecological validity (Burgess et al., 1998) and is dependent upon the functioning of the prefrontal cortex (Burgess et al., 2000, 2001, 2003). A previous study investigating multitasking in ASD demonstrated deficits in performance, although the nature of these deficits was not specified (Emslie et al., 2003). We believe that our multitask paradigm, in which we measure several cognitive processes contributing to multitasking, will enable us to elucidate more clearly the factors that underlie multitasking deficits in children with ASD. The pattern of relatively spared and impaired abilities is ASD enables us to make predictions about how children with HF-ASD will score on our multitask paradigm. Our hypotheses are outlined below.
9.2 Aims and hypotheses

In this study we aim to compare the multitask performance of a group of children with HF-ASD to a group of age, IQ and gender matched typically developing (TD) controls. In addition, we shall collect information on the everyday organisation difficulties experienced by children with HF-ASD using the parent form of the BRIEF questionnaire. We propose the following hypotheses:

[1] HF-ASD children will show impairments on some multitask variables relative to TD controls

We will compare scores on key multitask variables in HF-ASD and TD groups, and hypothesise that:

- **HF-ASD children and TD controls will be equally able to learn and retain the rules of the paradigm.** Children with HF-ASD have relatively good retrospective memory, in addition we will administer the multitask paradigm so that participants in both groups learn the rules.

- **HF-ASD children will demonstrate impaired planning and plan following relative to TD controls.** Planning deficits have consistently been observed in children with ASD. Although plan execution has not been investigated independently of planning in ASD, we predict that the ability to implement a plan will also be impaired on the basis of everyday organisational difficulties in children with HF-ASD.

- **HF-ASD children will demonstrate impaired multitask performance relative to TD controls.** Children with HF-ASD have difficulties organising future-oriented activities in their everyday lives of the sort which our multitask paradigm is designed to measure. Although multitasking deficits in ASD have been observed in one previous study, the processes underlying these deficits were not explored. Our multitask paradigm enables us to investigate which aspects of multitask performance present the greatest difficulty for children with HF-ASD. On the basis of the cognitive profile associated with ASD we hypothesise that strategic rule use and task switching will be most impaired in children with HF-ASD relative to TD controls.

- **No prediction re. how children with HF-ASD and controls will compare on the recount measure**

Performance monitoring, as measured by recount, may be impaired in children with HF-ASD if they have impaired functioning of the Supervisory Attention System (Siklos & Kerns, 2004). However, an investigation of prospective performance monitoring failed to show any deficits in this cognitive skill (Farrant *et al.*, 1999). We have no specific prediction for how children with HF-ASD will score on the recount measure.
[2] HF-ASD children will demonstrate elevated BRIEF Scores

Children with HF-ASD have difficulties organising activities in everyday life resulting in elevated BRIEF scores in this population. We anticipate that children in our sample will exhibit the same profile on the BRIEF, indicating their everyday organisation difficulties.

[3] Some multitask variables will correlate with BRIEF sub scales

Multitasking has a strong executive component and many of the questions in the BRIEF relate to the cognitive organisational skills that multitasking purports to measure. Indeed, there are parallels between some of the variables generated by multitasking and some of the sub scores of the BRIEF. Some of these variables and sub scales are based upon very similar cognitive constructs. We will investigate the relationships between these variables and sub scales by correlating multitask variables with BRIEF sub scales. We hypothesise that the following relationships will be significant:

- Multitask Plan and BRIEF Plan/ Organise - both dependent on planning
- Multitask Perform and BRIEF Initiate - both dependent on the ability to begin tasks independently
- Multitask Switch and BRIEF Initiate – both dependent on self-initiated actions
- Multitask Switch and BRIEF Shift – both dependent on cognitive flexibility
- Multitask Switch and BRIEF Inhibit – both dependent on inhibitory control
- Multitask Recount and BRIEF Monitor – both dependent on tracking goal-oriented behaviour
9.3 Method

9.3.1 Study design

This study is a between groups design using two independent samples: 16 typically developing children (TD controls) were recruited from two mainstream schools and 14 group of children with HF-ASD were recruited from two specialist clinical centres in the south east of England (Guy's Hospital and Harper House Children's Service).

9.3.2 Ethical considerations

Ethical approval for previous multitask studies was extended to include the TD control participants in this study. Ethical approval that had been granted to a number of ongoing projects involving participants with HF-ASD within our department was extended to this project. This ethical approval was accepted by the ethics panels of our two recruitment centres, and recruitment procedures were agreed with each centre. Parents of children in both groups received written information about the study and written parental consent was obtained for each child who participated, plus additional consent to video the test session. In addition, children were asked for verbal assent to participate. Children received a small prize for participating in the study (a pencil case with pens and a ruler).

9.3.3 Participants

**TD control participants:** were recruited from two mainstream schools that had participated in previous studies, one primary and one secondary. The Head Teachers were contacted first and with their endorsement letters were distributed to parents of children in target classes, one in each school. Class teachers collected the responses and the researchers (the Ph.D. candidate and an MSc. student) arranged testing times with them.

The participants with HF-ASD were recruited from two clinical centres specialising in the diagnosis of social communication disorders. Children from Guy's Hospital were recruited from an existing sample of children participating in an ongoing study of ASD, the Guy's South Thames Development and
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Communication Study. The participants from Harper House Children's Service were children who had been assessed and diagnosed by specialists at the clinic within the last 18 months.

**HF-ASD participants from Guys Hospital:** target families were selected from a larger sample of families already participating in a large-scale longitudinal study of HF-ASD, the South Thames Development and Communication Study. Families who met inclusion criteria (see next section) were selected from the study database by researchers working on the project. These families were provided with written information about the study. Families who wished to find out more about the study were asked to return a brief form giving their contact details. This form was returned to the PhD candidate who was then at liberty to contact the families to discuss the project further. Interested families were contacted by telephone and assessment dates arranged.

**HF-ASD participants from Harper House Children's Service:** in order to supplement the South Thames sample we sought to recruit children from the North Thames area via a specialist clinical service, Harper House. A target list was generated from centre records, which included children who had been involved with the service during the last 18 months and who were between 10 and 12 years old. In this instance the researchers hand-searched these patients' files to find children who met inclusion criteria (see next section). Families who met inclusion criteria were provided with written information about the study on behalf of the clinical service. Families who wished to find out more about the study were asked to return a brief form giving their contact details. This form was returned to

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1 The Guy's South Thames Development and Communication Study: as part of an ongoing prevalence study of autism spectrum disorders in 12 (former) health districts in South England, 150 10-to-12-year-old children with a current ICD-10 (WHO, 1993) clinical diagnosis of an autism spectrum disorder (F84.0 childhood autism, F84.1 atypical autism, F84.5 Asperger's syndrome) from local paediatric or psychiatric services were seen for a full research assessment. The assessment included the standard diagnostic research instruments the Autism Diagnostic Interview (ADI; Lord et al., 1994), the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1999, 2000) and the Social Communication Questionnaire (SCQ; formerly the Autism Screening Questionnaire; Berument et al., 1999), and standardised measures of intellectual WISC-III-UK; Wechsler, 1992) and language ability (CELF-R; Semel et al., 1987).

2 Harper House Children's Service is one of the leading diagnosis centres in the South of England. The experienced clinical team has contributed much to ASD research and clinical practice, having been involved in projects including the development of the Autism Diagnostic Interview (Le Couteur, Rutter, Lord et al., 1989)
the Ph.D. candidate who was then at liberty to contact the families to discuss the project further. Interested families were contacted by telephone and assessment dates arranged.

9.3.4 Inclusion criteria

TD control group: inclusion criteria were gender and age.

HF-ASD group: the sample recruited from Guys is very well characterised, recent information had been obtained for all children about diagnosis and intellectual ability using standardised measures. The sample from Harper House is less well characterised; for example information on levels of intellectual functioning (prior to testing) did not come from the same IQ measures. Despite differences in available information, participants were selected on the basis of the inclusion criteria in Table 9.1.

Table 9-1: Inclusion criteria for participants with HF-ASD

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Guys Hospital</th>
<th>Harper House</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact within last 18 months</td>
<td>All participants in this study had been assessed within the past 12 months</td>
<td>Include children who have been assessed within the last 18 months</td>
</tr>
<tr>
<td>Gender</td>
<td>All male sample selected</td>
<td>All male sample selected</td>
</tr>
<tr>
<td>Age</td>
<td>10-12 years</td>
<td>10-12-years</td>
</tr>
<tr>
<td>Current Diagnosis of HF-ASD</td>
<td>Clinical diagnosis: ICD-10 Consensus diagnosis(^1): score &gt; cut off on 2/3: ADI, ADOS, SCQ</td>
<td>Clinical diagnosis: ICD-10, DSM-IV</td>
</tr>
<tr>
<td>No co-morbid diagnoses(^2)</td>
<td>Computer database search excluded all children with a co-morbid diagnosis</td>
<td>Case note search excluded all children with a co-morbid diagnosis</td>
</tr>
<tr>
<td>IQ &gt; 80</td>
<td>WISC-III(^UK): FSIQ(^3), VIQ &amp; PIQ &gt; 80</td>
<td>Kaufmann, BAS(^4), WISC-III(^UK) &gt; 80</td>
</tr>
<tr>
<td>Language &gt;80</td>
<td>CELF-R TL(^5) &gt; 80</td>
<td>CELF-R TL &gt; 80(^6)</td>
</tr>
</tbody>
</table>

1. In addition to a clinical diagnosis, all participants in the Guy's sample met criteria for a consensus diagnosis of HF-ASD. This requires participants to score above algorithm cut off point on two of the following 3 measures of HF-ASD. The Autism Diagnostic Interview (ADI), the Autism Diagnostic Observation Schedule (ADOS) and the Social Communication Questionnaire (SCQ).

2. All children with co-morbid diagnoses were excluded, for example ADHD, conduct disorder (CD), Tourette's Syndrome, Epilepsy.

3. The WISC-III\(^UK\) generates measures of full-scale IQ (FSIQ), verbal IQ (VIQ) and performance IQ (PIQ), with a mean of 100, standard deviation of 15.

4. The Kaufmann and the British Ability Scales (BAS) are alternate tests of intellectual ability, scored with a mean of 100 and a standard deviation of 15.

5. The Clinical Evaluation of Language Functioning – Revised (CELF-R) yields a total language score with a mean of 100 and an SD of 15.

6. Information about the CELF-R was only available for 11 of 19 cases from Harper House.
9.3.5 Response rates

We invited all children who met inclusion criteria to participate in the study. **TD controls:** from 28 letters sent home in the secondary school, 9 boys and 12 girls responded positively, of whom 9 boys and 6 girls were assessed. At this stage it was established that the clinical sample would be all male, therefore the remaining 6 girls were not assessed (they were given a small prize and thanked for their interest in the study). In the primary school letters were distributed to boys only, 11 letters were sent out from which 7 positive responses were received. Therefore a total of 16 boys formed the TD control group. For participants with **HF-ASD:** 15 cases drawn from the Guy’s Hospital sample met inclusion criteria, letters were sent to all 15 families, 9 families responded positively and all 9 of these children were assessed. Nineteen children drawn from the Harper House Clinic met inclusion criteria. We wrote to 19 families asking them to participate in our research, 6 families responded positively, and 5 of these 6 children were assessed. A total of 14 boys formed the HF-ASD clinical group.

9.3.6 Measures

All children performed the multitask paradigm. Children in the control group and those recruited from Harper House were also assessed on baseline measures of IQ (see below). The children recruited from Guy’s Hospital had all been assessed for IQ during the past 12 months and we felt it would be counterproductive to repeat this assessment. Similarly, BRIEF parent forms had been collected for the 9 children in the Guy’s sample within the past 12 months. In order to have BRIEF ratings for the entire clinical sample, we obtained BRIEF parent forms from the 5 families recruited from Harper House.

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3 From an initial list of 79 male children aged between 10-12-years old, files were available for 75 individuals. Of these 75, 38 were excluded on the grounds of co-morbid diagnoses (19 ADHD, 1 ADHD/CD, 2 Conduct Disorder, 1 hyperactivity, 1 Tourette’s Syndrome, 5 SLI, 5 learning disabled, 1 cerebral palsy, 1 global developmental delay, 1 epilepsy and 1 other (sensory dormancy). Of the remaining 37 children, 18 did not meet criteria for either language ability or IQ (where they had been formally assessed).

4 A mutually convenient assessment time could not be arranged for one child due to the family moving house.
Battersea Multitask Paradigm

The multitask paradigm is identical to the paradigm used in previous studies: 3 tasks to be performed in 3 minutes governed by 4 rules. In this study we adopted a rule training administration procedure, as detailed in the multitask training study (Chapter 6). Participants were given up to three repetitions when learning the rules of the paradigm. We did this to ensure that clinical and control participants would have an equally good chance to learn and remember the rules. We did not anticipate that children in the clinical sample would have difficulties learning the rules, but we wanted to be sure that we didn't loose valuable clinical participants to this possibility. The multitask paradigm generates 6 key variables: rule learn, plan, plan follow, performance, recount and rule memory. In addition, multitask performance is broken down into task switch, strategic performance and penalty performance scores.

Wechsler Intelligence Scale for Children UK 3rd Edition – Short Form

The Wechsler Intelligence Scale for Children UK 3rd Edition (Weschler, 1992) is a widely used test of intellectual ability. The full version comprises 5 verbal sub tests and 5 performance (non-verbal) sub tests, and provides a measure of verbal, performance and full-scale IQ. Participants in the HF-ASD group recruited from Guys Hospital had been assessed on the full WISC-IIIUK within the last 12 months. We used a short form of this battery to obtain an IQ estimate for the remaining children in the study: the 5 children with HF-ASD recruited from Harper House and the 16 male controls. The WISC-III short form is reliable for research purposes (Kaufmann, Kaufmann, Balgopal et al., 1996) and includes 2 verbal sub tests (arithmetic and similarities) and two performance sub tests (block design and picture completion). This allows for verbal, performance and full-scale IQ estimates to be obtained.

Behaviour Rating Inventory of Executive Function (BRIEF)

The BRIEF is an 86 item parent and teacher questionnaire designed to assess executive function behaviours in everyday environments (Gioia et al., 2000). We collected a parent BRIEF questionnaire for each child in our clinical sample. The parents of children with HF-ASD recruited from Guy's Hospital had filled out a BRIEF within the last 12 months. The parents of the additional 5 children with HF-ASD recruited from Harper House also completed BRIEF forms.
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The BRIEF yields eight sub scales, each representing a domain of executive functioning; these are detailed in Table 9.2. The sub scales in turn contribute to three index scores, a 'behaviour regulation index,' a 'metacognition index' and a summary index the 'global executive composite.' Two further scales are built into the questionnaire to assess validity. An inconsistency scale estimates how consistent or not the respondent has been when filling out the questionnaire (scores ≤4 acceptable). A negativity scale assesses whether the respondent appears to have an excessively negative perception of the child (scores ≤6 acceptable).

Each of the 86 items in the BRIEF is rated by the parent as occurring never, sometimes, often; these responses are scored as 0, 1 or 2 point answers. The raw scores for each sub scale are linearly transformed into T-scores, which have a mean of 50 and a standard deviation (SD) of 10. A T-score of above 70 means that the child's behaviour is rated as being 2 SD above the standardisation sample mean. T-scores at or above 65 should be considered as having potential clinical significance. Questions from the BRIEF and the sub scales they contribute to are detailed in Appendix 5.

Table 9-2: BRIEF sub scales and index scores

<table>
<thead>
<tr>
<th>BRIEF sub scale</th>
<th>What the executive function the sub scale measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhibit</td>
<td>Inhibitory control</td>
</tr>
<tr>
<td>Shift</td>
<td>Cognitive flexibility</td>
</tr>
<tr>
<td>Emotional control</td>
<td>Ability to modulate excessive emotional responses</td>
</tr>
<tr>
<td>Initiate</td>
<td>Ability to begin tasks independently and generate thoughts and ideas</td>
</tr>
<tr>
<td>Working Memory</td>
<td>Capacity to hold information in mind for the purpose of completing a task</td>
</tr>
<tr>
<td>Plan/ Organise</td>
<td>Ability to manage current and future oriented demands</td>
</tr>
<tr>
<td>Organisation of</td>
<td>Ability to organise one's world and keep track of possessions</td>
</tr>
<tr>
<td>Materials</td>
<td>Ability to keep track of goal-oriented behaviour</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BRIEF index scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behaviour Regulation Index (BRI)</td>
</tr>
<tr>
<td>Metacognition Index (MI)</td>
</tr>
</tbody>
</table>

All sub scales contribute to the Global Executive Composite (GEC)
9.3.7 Procedure

TD Control children were assessed at school in a quiet room. HF-ASD children were assessed in a private quiet room either at school or at home. All participants were seated on one side of a testing table, directly opposite the experimenter. A video camera was placed beside the experimenter and the entire assessment session videotaped. Tasks were administered as part of an extended test battery, only the results of the IQ measures and the multitask are reported here. The whole battery took approximately 70 minutes to administer, with a 15-minute break halfway through. The order of task administration was kept constant across participants; testing began with a picture-sequencing test (not reported here) after which two of the WISC-IIIsub tests (arithmetic and picture completion) were administered, then the Battersea Multitask Paradigm. Following the break, the remaining two WISC-IIIUK sub tests were administered (block design and similarities) followed by other tests not reported here (card sorting and strange stories). The order of tasks in the Battersea Multitask Paradigm was counterbalanced across participants. Children recruited from Guys Hospital followed the same order of test administration but did not perform the WISC-IIIUK sub tests. The BRIEF was posted to parents of the 5 children recruited from Harper House immediately after they had been assessed. Research staff working on the South Thames Development and Communication Study provided BRIEF scores for the Guy’s Hospital sample.
9.4 Results

9.4.1 Participant groups

Sixteen typically developing children and 14 children with HF-ASD participated in the study: all participants were male. The groups were well matched for age: TD mean = 11 years 11 months (SD = 6.36, range = 130-151 months) and HF-ASD mean = 12 years 0 months (SD = 8.89, range = 122-154 months). All participants in the HF-ASD group had a current clinical diagnosis of autism spectrum disorder (ICD-10, DSM-IV). Nine children had a diagnosis of childhood autism (6 from Guy’s, 3 from Harper House) and 5 children had a diagnosis of Asperger’s (3 from Guy’s, 2 from Harper House). All TD controls and 12 of 14 children with HF-ASD attended mainstream schools. Attendance at primary and secondary schools was evenly balanced between groups. The groups were well matched for measures of full-scale, verbal and performance IQ, see Table 9.3. One-way analyses of variance revealed no significant differences between the groups on any of these measures.

Table 9-3: Group scores on IQ measures

<table>
<thead>
<tr>
<th>Group (N)</th>
<th>Full-scale IQ</th>
<th>Verbal IQ</th>
<th>Performance IQ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>TD (16)</td>
<td>109.1 (12.9)</td>
<td>91-133</td>
<td>110.2 (16.4)</td>
</tr>
<tr>
<td>HF-ASD (14)</td>
<td>105.6 (12.9)</td>
<td>86-127</td>
<td>105.8 (17.4)</td>
</tr>
</tbody>
</table>

9.4.2 Group comparisons on multitask variables

The multitask paradigm generates six key variables and some other multitask performance scores. Group comparisons on these variables and scores are outlined below. Examination of the data identified one child in the HF-ASD group who obtained poorer scores on many aspects of multitasking. Removing this child from the analysis did not change the group differences observed; therefore the results reported here are for 16 TD controls and 14 HF-ASD participants.
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[1] Rule Learning and Memory
We hypothesised that children in both groups would be equally able to learn and remember the rules of the multitask paradigm. Rule learning and memory scores are detailed in Table 9.4 along with the mean number of repetitions of the rules required by each participant group. The rule learning score was calculated as the participant’s free-recall rule learning score on the first occasion on which they learned all four rules (this might be on the 1st, 2nd or 3rd repetition, scored out of 8 points), plus their cued recall score, answers to a series of questions about the rules (scored out of 10 points). All participants met criteria of being able to learn the four rules after a maximum of 3 repetitions.

Table 9-4: Rule learning and rule memory scores

<table>
<thead>
<tr>
<th>Group (N)</th>
<th>Rule Learning (max 18)</th>
<th>Rule Memory (max 18)</th>
<th>Repetitions (1-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>TD (16)</td>
<td>17.31 (0.79)</td>
<td>16-18</td>
<td>16.87 (1.02)</td>
</tr>
<tr>
<td></td>
<td>1.81 (0.83)</td>
<td>1-3</td>
<td></td>
</tr>
<tr>
<td>HF-ASD (14)</td>
<td>16.86 (1.23)</td>
<td>14-18</td>
<td>15.42 (2.47)</td>
</tr>
<tr>
<td></td>
<td>1.28 (0.61)</td>
<td>1-3</td>
<td></td>
</tr>
</tbody>
</table>

One way between subjects analysis of variance indicated no significant group differences in rule learning performance \[F (1,28) = 1.49, \text{NS.}\]. This was true of free recall rule learning \[\text{TD mean} = 7.75 (\text{SD} = 0.45), \text{HF-ASD mean} = 7.78 (\text{SD} = 0.42): F (1,28) = .05 \text{NS.}\] and cued recall rule learning \[\text{TD mean} = 9.56 (\text{SD} = 0.63), \text{HF-ASD mean} = 9.07 (\text{SD} = 1.07): F (1,28) = 2.42 \text{NS.}\]. Nor did the groups differ in the number of repetitions required to meet rule learning criteria \[F (1,28) = 3.79, \text{NS.}\]. The groups were also equally able to remember the rules of the multitask paradigm. Group comparisons for rule memory failed to meet criteria for homogeneity of variance (Levene’s statistic), using a Mann-Whitney U test no significant differences in rule memory were found \[z = -1.86, \text{NS.}\].

[2] Planning and Plan-Following
Children with HF-ASD were expected to obtain lower scores on the planning measure. This prediction was made on the basis of literature supporting significant planning difficulties in HF-ASD. Our hypothesis was supported by the data: mean planning and plan following scores are detailed in Table 9.5. Group differences in planning were investigated using a non-parametric Mann-Whitney U test: significant group differences were observed \[z = -2.93, p< .05\].
Table 9-5: Planning and plan following scores

<table>
<thead>
<tr>
<th>Group (N)</th>
<th>Planning (max 12)</th>
<th>Plan Following (max 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
</tr>
<tr>
<td>TD (16)</td>
<td>10.81 (1.47)</td>
<td>9-12</td>
</tr>
<tr>
<td>HF-ASD (14)</td>
<td>8.21 (3.09)</td>
<td>3-12</td>
</tr>
</tbody>
</table>

The plan following score represents the extent to which a participant enacted their original plan. As such, it is yoked to the planning score and group comparisons for plan following must be considered after group differences in planning scores have been accounted for. Although analysis of variance revealed significant group differences for plan following \([F (1,27) = 12.77, p < .01]\), these differences did not remain significant after Analysis of Covariance (ANCOVA) was performed, co-varying for the effect of planning \([F (1,27) = 2.86, \text{NS}; \text{estimated marginal means TD mean} = 9.70 (\text{standard error, SE} = .42), \text{HF-ASD mean} = 9.48 (\text{SE} = .46)]\). These results indicate that despite the seemingly large group differences in the means for plan following, children in both groups were equally able to implement the plan they had formed.


Our hypothesis was that children with HF-ASD would perform the multitask paradigm less efficiently than TD controls. This hypothesis was largely supported by the data; multitask performance means are detailed in Table 9.6. Group comparisons were performed using a Mann-Whitney U test, results indicated a significant group difference for multitask performance \([z = -2.11, p< .05]\).

Table 9-6: Multitask performance scores

<table>
<thead>
<tr>
<th>Group (N)</th>
<th>Multitask Performance (max 20)</th>
<th>Strategic Performance (max 18)</th>
<th>Penalty Performance (number of participants)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>TD (16)</td>
<td>16.62 (3.22)</td>
<td>9-20</td>
<td>15.37 (2.27)</td>
</tr>
<tr>
<td>HF-ASD (14)</td>
<td>12.71 (5.61)</td>
<td>1-19</td>
<td>13.28 (4.03)</td>
</tr>
</tbody>
</table>

Multitask performance score is a composite score, representing the combination of strategic aspects of performance (strategic rule use), aspects of performance for which participants are penalised...
(placement errors and rule breaking) and the switch strategy adopted by participants. We investigated which of these aspects of performance contributed to group differences in overall multitask performance.

(a) Strategic performance: the mean scores for strategic performance are also detailed in Table 9.6. No significant differences were observed between the groups for strategic performance, Mann-Whitney U, z = -1.44, NS.

(b) Penalty performance: the number of children in each group who made errors or broke the rules is detailed in Table 9.6. Only one child in each group made a placement error. However, 7 of 14 children with HF-ASD broke the rules of the paradigm compared to 2 of 16 TD participants, this difference was significant: $\chi^2 = 5.00$, df = 1; p < .05.

(c) Task switch performance: task switch scores for both groups together ranged from 0 to 19, these are illustrated in Figure 9.1. As outlined previously, the lower limit of an efficient switch strategy was 3 switches. In the present study the upper limit was set at 11 switches. This was because only one child switched more than 11 times and this child switched between tasks without considering where items were placed, an inefficient switch strategy. Thus an efficient switch strategy was determined as being between 3 and 11 switches.

Figure 9-1: Distribution of number of task switches – both groups
We hypothesised that children in the HF-ASD group would switch between tasks less efficiently than children in the TD control group, on the basis of research indicating that decreased cognitive flexibility is a hallmark of ASD. Further, we hypothesised that inefficient task switching would be due to perseveration on a few tasks rather than rapid switching between many tasks. This hypothesis was supported by the pattern of our results: 6 children with HF-ASD (43%) adopted an inefficient switch strategy, compared to only 2 TD control children (13%). However, this difference failed to reach significance between groups [$\chi^2 = 3.52$, df = 1; NS.]. Of the 6 children with HF-ASD who adopted an inefficient strategy, 5 did not to switch between tasks very often with only 1 child in this group switching rapidly between tasks. The percentage of children in each group who adopted an inefficient or efficient switch strategy is illustrated in Figure 9.2 below.

**Figure 9-2: Task switch score (% of participants who select inefficient and efficient switch strategies)**

![Figure 9-2: Task switch score (% of participants who select inefficient and efficient switch strategies)](chart)

[4] Recount

Both groups scored well on the recount measure with the TD control group performing at ceiling (mean = 9.00, SD = 0.00). Although the HF-ASD group achieved somewhat lower scores (mean = 7.93, SD = 2.05) this difference was not significant: Mann-Whitney U test [$z = -1.83$, NS.].

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As we had anticipated, planning scores were significantly different between groups, with HF-ASD children forming less strategic plans that TD controls. In the multitask paradigm planning is scored by assessing the content of verbal output and the volume of this verbal output is likely to be influenced by verbal fluency. Verbal fluency is often reduced in children with ASD compared to typically developing children (Hughes et al., 1994). Although our groups were matched for verbal IQ, we did not measure verbal fluency directly. Therefore, it is possible that children with HF-ASD demonstrate poor planning scores not because of planning difficulties per se, but due to simply saying less, rendering less verbal output to be scored.

To investigate potential group differences in verbal fluency, we measured (1) the total time participants took to plan or recount, (2) participants’ verbal output (number of words generated) and (3) their verbal fluency (number of words generated per second). This enabled us to assess verbal output and verbal fluency under planning and non-planning conditions, providing some internal means of controlling for verbal output independent of planning. If planning itself presents difficulties for HF-ASD participants, we would expect their verbal output to be higher under recount conditions than planning conditions compared to controls. Verbal output and verbal fluency scores are detailed in Table 9.7.

<table>
<thead>
<tr>
<th>Group (N)</th>
<th>Plan verbal output scores (means and standard deviations)</th>
<th>Recount verbal output scores (means and standard deviations)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total time for plan output (seconds)</td>
<td>Number of words generated</td>
</tr>
<tr>
<td>TD (16)</td>
<td>16.26 (7.93)</td>
<td>35.87 (17.8)</td>
</tr>
<tr>
<td>HFASD(14)</td>
<td>15.11 (6.57)</td>
<td>20.07 (16.39)</td>
</tr>
</tbody>
</table>

Plan: no group differences were observed in the time taken to plan [F (1,28)=0.19, NS.]. The TD control group produced significantly more words in their plan than the HF-ASD group [F (1,28)=6.33, p< .05] and generated these words at a significantly faster rate [F (1,28)=8.92, p< .01].
Recount: HF-ASD participants took significantly more time to recount their actions than TD controls \([F(1,28)=5.73, p<.05]\); however both groups generated a similar number of words \([F(1,28)=0.03, \text{NS.}]\), resulting in the TD controls generating more words per second during recount \([F(1,28)=5.81, p<.05]\).

Plan versus Recount: within subjects analyses of variance were used to investigate whether the rate of words generated per second differed between planning and recount. This enabled us to assess whether verbal fluency changed under planning and non-planning conditions within each group. Neither the HF-ASD \([F(1,13)=1.89, \text{NS.}]\) nor the TD control group \([F(1,15)=3.89, \text{NS.}]\) generated significantly more words per second when recounting than they did when planning.

Analysis of covariance: we re-investigated the original group difference in planning, this time co-varying for verbal fluency during planning (verbal fluency measured by rate of words generated per second). Results indicate once that group differences in verbal fluency are accounted for, no significant group differences in planning remain: ANCOVA, \(F(1,27)=2.01, \text{NS.}\); estimated marginal means: TD controls mean = 10.16 (SE = .54), HF-ASD mean = 8.95 (SE = .59).

We discuss what these data mean for our original question - is it possible that poor planning scores in the HF-ASD group are simply the result of reduced verbal fluency? First, although reduced verbal fluency in the HF-ASD group was observed during both planning and recounting, low verbal fluency does not necessarily lead to a low score on a multitask variable. Verbal fluency was reduced in planning and significant group differences in planning were observed. However, verbal fluency was also reduced during recounting where no significant group differences were observed. This implies that the group differences in planning are the result of planning deficits in the HF-ASD group. However, group differences in planning do not remain significant after verbal fluency is taken into account – suggesting that differences in verbal fluency may in fact influence planning scores. In sum, we cannot rule out the possibility that the planning differences observed between our groups may be attributable to group differences in verbal fluency. In future studies, an independent measure of verbal fluency should be used, and a non-verbal measure of planning designed.
9.4.3 BRIEF profile of the HF-ASD group

BRIEF scores are derived from parent ratings of children's everyday executive functioning. We present scores on 8 sub scales and 3 index scores; each has a mean of 50 and a standard deviation of 10. Scores above 70 are 2 standard deviations above the mean. On the basis of previous research, we hypothesised that the profile of BRIEF scores in our sample of boys with HF-ASD will be one of generally elevated scores, with a noticeably high score on the 'shift' sub scale indicative of cognitive inflexibility. Mean BRIEF scores and standard deviations for the HF-ASD group are detailed in Table 9.8. Overall the results support this profile, mean scores are elevated on all sub scales of the BRIEF and 'shift' is the most elevated sub scale of all. Parents rate sub scales contributing to the behaviour regulation index more highly (thus more problematic) than they rate sub scales contributing to the metacognition index. The global executive composite score is above 70, more than 2 standard deviations above the mean.

Table 9-8: BRIEF scores for the HF-ASD group

<table>
<thead>
<tr>
<th>BRIEF Sub Scale / Index</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
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</thead>
<tbody>
<tr>
<td>Inhibit</td>
<td>71.78</td>
<td>9.61</td>
<td>58-86</td>
</tr>
<tr>
<td>Shift</td>
<td>77.00</td>
<td>8.90</td>
<td>56-92</td>
</tr>
<tr>
<td>Emotional Control</td>
<td>70.21</td>
<td>7.63</td>
<td>53-88</td>
</tr>
<tr>
<td>Behaviour Regulation Index</td>
<td>76.64</td>
<td>7.71</td>
<td>67-93</td>
</tr>
<tr>
<td>Initiate</td>
<td>63.14</td>
<td>9.69</td>
<td>47-77</td>
</tr>
<tr>
<td>Working Memory</td>
<td>63.93</td>
<td>8.76</td>
<td>47-78</td>
</tr>
<tr>
<td>Plan/ Organise</td>
<td>64.78</td>
<td>9.69</td>
<td>47-77</td>
</tr>
<tr>
<td>Organisation of Materials</td>
<td>60.93</td>
<td>8.13</td>
<td>43-69</td>
</tr>
<tr>
<td>Monitor</td>
<td>69.86</td>
<td>6.90</td>
<td>54-81</td>
</tr>
<tr>
<td>Metacognition Index</td>
<td>66.36</td>
<td>7.46</td>
<td>51-77</td>
</tr>
<tr>
<td>Global Executive Composite</td>
<td>71.78</td>
<td>7.49</td>
<td>57-82</td>
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</table>
9.4.4 Correlating multitasking and BRIEF scores

We planned to investigate the relationship between specific multitask scores and BRIEF index scores, as there are theoretical parallels between some of the variables generated by multitasking and some of the sub scores of the BRIEF. We correlated the key multitask variables (including switch) with the eight BRIEF sub scales, with age in months and Full-scale IQ partialled out. The resulting Pearson correlation matrix is shown in Table 9.9.

The results in Table 9.9 show that multitask scores do correlate with the BRIEF scores. Some of the variables that we had anticipated would correlate did: multitask perform and BRIEF initiate ($r = -.59$, $p = .04$) and multitask switch and BRIEF initiate ($r = -.64$, $p = .02$). For other variables we failed to find the anticipated relationships: multitask plan and BRIEF plan/organise ($r = -.04$, NS), multitask switch and BRIEF inhibit ($r = -.24$, NS), multitask switch and BRIEF shift ($r = -.32$, NS) and multitask recount and BRIEF monitor ($r = -.26$, NS). Some unanticipated relationships found between variables are: multitask rule learn and BRIEF inhibit ($r = -.64$, $p = .02$), multitask rule learn and BRIEF working memory ($r = -.59$, $p = .04$), multitask switch and BRIEF working memory ($r = -.63$, $p = .02$), multitask recount and BRIEF initiate ($r = -.67$, $p = .02$), multitask working memory and BRIEF inhibit ($r = -.61$, $p = .03$) and multitask rule memory and BRIEF shift ($r = -.65$, $p = .02$). These results will be considered further in the discussion.
Table 9-9: Partial Correlation Matrix of Multitask Variables with BRIEF Sub Scales (age in months and FSIQ partialled out)

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<td>Plan</td>
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<tr>
<td>Follow</td>
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<tr>
<td>Perform</td>
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<td>-.15</td>
<td>.26</td>
<td></td>
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<td>.81***</td>
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<tr>
<td>Recount</td>
<td>.63*</td>
<td>.18</td>
<td>.52</td>
<td>.69*</td>
<td>.59*</td>
<td>.81***</td>
<td></td>
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<tr>
<td>Memory</td>
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<td>.10</td>
<td>.05</td>
<td>.37</td>
<td>.23</td>
<td>.27</td>
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<tr>
<td>Inhibit</td>
<td>.64*</td>
<td>.17</td>
<td>-.09</td>
<td>-.26</td>
<td>-.24</td>
<td>-.14</td>
<td>-.61*</td>
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<tr>
<td>Emot. Ctrl</td>
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<td>.19</td>
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<td>-.14</td>
<td>-.59*</td>
<td>-.64*</td>
<td>.67*</td>
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<td>.41</td>
<td>.21</td>
<td>.66*</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Plan/ Org.</td>
<td>-.29</td>
<td>-.04</td>
<td>.10</td>
<td>-.08</td>
<td>-.31</td>
<td>.11</td>
<td>-.21</td>
<td>.57</td>
<td>.51</td>
<td>.28</td>
<td>.50</td>
<td>.80**</td>
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<tr>
<td>Org. Mat</td>
<td>-.05</td>
<td>-.20</td>
<td>-.34</td>
<td>-.47</td>
<td>-.53</td>
<td>-.31</td>
<td>.09</td>
<td>.24</td>
<td>-.26</td>
<td>.02</td>
<td>.26</td>
<td>.42</td>
<td>.16</td>
<td></td>
</tr>
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<td>Monitor</td>
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<td>.03</td>
<td>-.05</td>
<td>-.27</td>
<td>-.23</td>
<td>-.26</td>
<td>-.37</td>
<td>.68*</td>
<td>.46</td>
<td>.16</td>
<td>.61*</td>
<td>.48</td>
<td>.68*</td>
<td>-.14</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001

Significant relationships between multitask and BRIEF variables are highlighted in bold and shaded grey.

Relationships we had anticipated might be significant are in boxes.
9.5 Discussion

In this study we found multitasking deficits in high functioning children with autism spectrum disorder compared to age, gender and IQ matched typically developing controls. We had predicted these deficits on the basis that children with HF-ASD have difficulties organising future actions in their day-to-day lives. Our results confirm and extend those of one previous study, as we were able to investigate the factors underlying the multitasking deficit observed. We found that compared to typically developing controls, children with HF-ASD exhibited deficits in planning and had difficulty switching fluently between tasks and avoiding rule breaking during multitask performance. These results are consistent with the cognitive profile of executive dysfunction in autism, which is one of poor planning and cognitive inflexibility. Parents of children with HF-ASD rated these everyday difficulties as occurring more frequently than might be expected in children of this age. Some evidence of a direct relationship between parent ratings and child multitask performance was found. These results and their implications are discussed below.

The groups were well matched on baseline measures of age, gender and IQ. Unfortunately we were limited to collecting only some baseline IQ data at the time of study, as 9 children in the clinical sample had already completed extensive IQ testing within the past 12 months. Therefore not all children were assessed on IQ measures at the same time as they performed the multitask paradigm. All children in the clinical group had IQ scores within the normal range and a clinical diagnosis of ASD; therefore they were a High Functioning Autism Spectrum Disorder (HF-ASD) group. Additional information was available for 9 of the 14 children with HF-ASD; these 9 children had both a clinical diagnosis of ASD and a 'criterion diagnosis' (score above algorithm cut off on 2 of 3 standard research instruments, ADOS, ADI and SCQ). A criterion diagnosis is becoming an increasingly recognised method of ensuring that research samples are well defined, enabling comparisons between studies (MRC Review of Autism Research, 2001). In future it will be beneficial to use this method of characterising a sample in addition to a clinical diagnosis. Both groups had an even mix of children attending either primary or secondary education. This may be an important factor to balance between groups, as the time tabling of classes in secondary education places greater demands on the ability to flexibly organise multiple activities. All control children, and the majority of children with HF-ASD (12 of 14), attended
mainstream schools. Finally, response rates for both our clinical and control groups were not as good as we had hoped. This leaves us open to the possibility that the sample could be biased towards children who do, or do not, have difficulties in the organisation of future action.

Turning to specific multitask variables, as predicted the groups demonstrated an equivalent ability to learn and retain the rules governing multitask performance and did not differ in the number of repetitions required to learn these rules. This result was anticipated as we designed the study to ensure that rule learning would be equal between groups. Furthermore, our results are in accord with studies that have failed to show retrospective memory impairments in individuals with ASD (Bennetto et al., 1996) and research which suggests that individuals with HF-ASD may exhibit superior retrospective memory abilities, for example in rote learning information (Ozonoff et al., 2002). We wanted to be sure that the good rule learning exhibited by children in our study stemmed from an understanding of the rules as much as from the ability to learn them by rote. Rule learning in the multitask study is assessed by free recall (which could reflect rote learning) and by cued recall (where participants' knowledge of the rules is assessed via a series of questions). No significant group differences were observed for either of these scores indicating that participants in both groups understood the rules they had learned and rule learning in the HF-ASD group was not merely facilitated by superior rote learning skills. This conclusion is supported by the lack of significant group differences in post-performance memory for the rules, showing that children had learned the information well enough to retain it over a period of time during which they were otherwise occupied.

Planning differences were observed between the groups: children with HF-ASD provided significantly less strategic plans than their TD controls. This result is in accordance with the difficulties planning ahead that children with HF-ASD are reported to have at home and at school (Ozonoff et al., 2002). Although many studies have reported planning deficits in ASD (e.g., Bennetto et al., 1996; Geurts et al., 2004; Ozonoff et al., 1991, 2004; Ozonoff & Jensen, 1999), these deficits tend to be on tasks with clearly defined goals such as tower tasks. Our multitask paradigm taps the ability to plan multiple tasks in a complex environment in which the goals are largely self-determined, which is more characteristic of planning in everyday life. Planning scores in this study were reliant on verbal output and it remains a matter of debate whether reduced verbal fluency influenced the group differences observed. This
debate is hampered by the fact that we only measured verbal fluency post-hoc, failing to measure it independently of our paradigm. In hindsight, we should have taken an independent measure of verbal fluency and considered any group differences on this measure when comparing planning scores. In future studies of multitasking, non-verbal planning scores should be derived, although it is difficult to see how this could be separated from performance. In terms of plan following, children with HF-ASD in this study did not have difficulty implementing the plans they had formed, however poor these may have been. Plan following scores, though yoked to planning scores, did not differ significantly between groups. This result is somewhat surprising given the everyday organisation difficulties experienced by children with HF-ASD and merits further research.

Significant group differences in multitask performance were anticipated and found. Multitask performance tests the child’s ability to perform multiple interleaved activities under time- and rule-based constraints. Participants are unable to attend to all the to-be-performed activities at one time, so must generate an intention to switch from one activity to another. Furthermore, the success with which the to-be-performed activities are accomplished is dependent on how the individual manages the constraints of the situation (in this instance, the rules). In this way multitasking taps the cognitive processes underlying the organisation of multiple, future-oriented actions in everyday life (Burgess, 2000; Burgess et al., 2000). Given the difficulties that children with HF-ASD have organising and scheduling activities in their day-to-day lives (Ozonoff et al., 2002) we had anticipated the multitask performance deficits we found. Our results correspond with those of one previous study in which children with HF-ASD exhibited impaired performance on a different multitask paradigm (Emslie et al., 2003). Moreover, our results extend this previous research as we investigated what might underlie this multitasking deficit.

The multitask performance variable is a composite score measuring task switching, strategic rule use and error making/rule breaking behaviour. We hoped that by examining specific aspects of performance, we would be able to identify which of these contributed most to the overall multitasking deficit observed. Our results indicate that individually the majority of these measures fail to reach levels of significant difference between the groups. However, cumulatively they combine to produce a difference in overall multitask performance. Therefore when interpreting these results, we shall
consider the overall pattern of impaired performance in the absence of significant group differences. There is a consistent pattern of greater variability across many performance variables in the HF-ASD group compared to the TD control group. This indicates that some children with HF-ASD were performing as well as controls on the multitask, whilst others were under-performing relative to controls.

Very few participants in either group made performance errors, but significantly more participants with HF-ASD broke the one-by-one rule than controls. This was more likely to represent a lack of on-line performance monitoring rather than forgetting that the rule existed, as children were able to recall this rule post performance. Deficits in inhibitory control have been reported in children with ASD (Geurts et al., 2004; Nyden et al., 1999) and these could also account for increased rule breaking.

Contrary to expectations, no group differences in strategic rule use were observed. Strategic rule use measures how effectively an individual maximises performance given the constraints of the situation. We had predicted that children with HF-ASD would be impaired on this aspect of multitasking, as children with ASD may have an impaired ability to use high-level, complex rules (Pennington & Ozonoff, 1996). Some children in the HF-ASD group were extremely good at applying the rules of the paradigm, whilst others clearly had difficulties with this aspect of the task (range of scores 4-18/18). Therefore, although the mean score for children in the HF-ASD group was lower than that of controls, the range of scores in the HF-ASD group likely precluded significant group differences. Closer examination of the data revealed that 4 children with HF-ASD scored less than or equal to 10 points on this measure, no TD control children obtained such low scores. In future we intend to perform analyses with sub groups like this one, to investigate how children who score poorly on multitask performance variables do on other multitask and BRIEF variables.

Task switching measures the efficiency with which participants switch between tasks in the paradigm. We had expected this skill to be impaired in children with HF-ASD on the basis of their poor cognitive flexibility and results from studies indicating their perseveration in switching set (e.g., Geurts et al., 2004; Ozonoff et al., 1991, 2004; Szatmari et al., 1990). Poor task switching in children with ASD has been interpreted in terms of the Norman and Shallice supervisory model of action control (Hughes et al., 1994). Hughes and colleagues (1994) suggest that perseveration occurs where behaviour is
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guided by the current activity and environment, represented in the model by the low-level 'contention scheduling' process. When the higher-level supervisory control system fails to interrupt the ongoing activity, this results in perseverative behaviour. Six children in the HF-ASD group failed to switch efficiently between tasks; of these 5 demonstrated perseverative switching. This result failed to reach significance as 2 children in the TD control group also exhibited inefficient perseverative switching. Further research will be necessary to clarify whether switching in multitasking presents a specific problem for children with HF-ASD, and if appropriate to determine the impaired cognitive processes underlying this switching deficit. Two current pieces of evidence are pertinent to this question.

First, there is evidence to suggest that switching difficulties are apparent in both children with HF-ASD and in children with a different developmental disorder, ADHD. In three studies which have investigated multitasking in children with ADHD, two found evidence of impaired task switching (Clark \textit{et al.}, 2000; Siklos & Kerns, 2004) whilst one did not (Kliegel & Kerber, \textit{in prep.}). In Kliegel and Kerber's study, although boys with ADHD switched between tasks as often as controls, this appears to have been at the expense of accuracy, as boys with ADHD made significantly more errors in their answers to stimuli on the tasks than did controls. All three studies report that children with ADHD did not break the rules of the multitask paradigm significantly more than controls. Comparing the results from these ADHD studies to ours, it seems that children with ADHD are impaired in their ability to switch efficiently between tasks, don't break the rules governing task performance and do make performance errors. In comparison, children with HF-ASD also have difficulties switching between tasks, but do break the rules of the paradigm more than controls and make few performance errors. Performance errors may be attributable to monitoring failures; thus children with ADHD may exhibit a deficient ability to monitor their ongoing performance (Siklos & Kerns, 2004). As discussed above, rule breaking may be attributed to poor inhibitory control and inhibition deficits have been observed in both children with ADHD and ASD (Geurts \textit{et al.}, 2004; Nyden \textit{et al.}, 1999). These performance differences need to be explored in a study in which children with ADHD and ASD are assessed using the same multitask paradigm.

Second, in addition to investigating the presence of switching deficits in children with HF-ASD, further research should be aimed at identifying the cognitive processes underlying these deficits. It is tempting
to hypothesise that switching deficits in ADHD and HF-ASD may be attributable to different underlying causes. Recall that in the process model of prospective memory (Kliegel et al., 2002), the successful execution of an intention relies on both inhibitory control (to inhibit attention to the ongoing task) and cognitive flexibility (to switch attention from the current to the prospective task). Deficits in inhibitory control are well documented in ADHD (e.g., Barkley, 1997) and children with ASD have poor cognitive flexibility (Geurts et al., 2004, Ozonoff et al., 2004, Ozonoff & Jensen, 1999). In support of this hypothesis, Siklos and Kerns (2004) reported that task switching in their multitask paradigm correlated with measures of response inhibition and with parent rated hyperactive/ inattentive symptoms on a standard behaviour rating scale (the Conner's Parent rating Scale – Revised). Kliegel (2003b) has recently designed a version of the HEXE multitask paradigm that includes high and low inhibition conditions. It would be interesting to investigate the effect of this within task manipulation on task switching in children with ASD and ADHD. Switching in multitask paradigms is also seen as a measure of prospective memory, representing the ability to activate and execute previously generated intentions. This raises the question of whether switching deficits in HF-ASD arise from impaired cognitive flexibility, impaired prospective memory, or both. In future studies of multitasking in HF-ASD independent measures of both cognitive flexibility and prospective memory should be taken. A within task manipulation akin to Kliegel's inhibition manipulation would also be desirable.

Finally, no significant group differences on the recount measure were found. We had not formed a specific hypothesis about how the groups would compare on this measure. Group comparisons for recount were complicated by the fact that the TD control group performed at ceiling, whilst the scores of the HF-ASD showed greater variability. We have discussed the limitations of the recount measure in previous chapters. The ability to recount what was achieved during performance may rely on metacognitive skills, and these may or may not be impaired in individuals with autism (Farrant et al., 1999). The BRIEF questionnaire has a ‘metacognition index,’ and the children in our study did not score as highly on this (high score = greater difficulties) as they did on the behaviour regulation index. This result is discussed further below.

In sum, the results of the present study support an overall deficit in multitask performance in children with HF-ASD compared to TD controls, extending a previous study of multitasking in children with ASD.
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Task switching difficulties may contribute to this overall deficit, although this hypothesis needs further investigation. Similarly, impaired strategic rule use may play a role in the performance deficit observed in some children with HF-ASD, but not others. Children with HF-ASD were more likely to break the rules of the paradigm than TD controls, but not to make performance errors. In future it may prove fruitful to investigate the presence of sub groups of children with HF-ASD who performed poorly on different multitask performance variables, is it the same children perform poorly on all these variables? Finally, the pattern of results observed bears similarities and differences with investigations of multitasking in children with ADHD.

We had predicted that the children with HF-ASD in our study would demonstrate the sorts of everyday organisation difficulties commonly reported in children with autism spectrum disorder. The BRIEF questionnaire is designed to assess executive function behaviours in everyday environments and many of the questions contained in it relate to the planning and organisation of activities. As such we believed that the BRIEF would be a good way to evaluate whether the children with HF-ASD in our study actually have everyday organisation difficulties.

The BRIEF scores observed in our clinical sample indicate that the children do indeed have significant difficulties with executive control in their day to day lives. Mean scores were elevated across all eight sub scales of the BRIEF with the 'shift' sub scale being the most elevated. This profile is entirely consistent with profiles generated for children with HF-ASD in two other studies investigating the clinical validity of the BRIEF (Gioia et al., 2000; Gioia et al., 2002). In our study, scores on the three sub scales contributing to the behaviour regulation index (BRI) were higher than scores on sub scales contributing to the metacognition index (MI), although all scores were elevated relative to norms. The BRI sub scales are inhibit, shift and emotional control. The MI sub scales are initiate, working memory, plan/ organise and organisation of materials. This pattern of results had not been anticipated as we had expected children with HF-ASD to have metacognitive difficulties in addition to behaviour regulation problems. This expectation was based upon literature supporting high-level planning and organising difficulties in this clinical group (Bennetto et al, 1996; Geurts et al., 2004; Hughes, 2001; Ozonoff et al., 1991). We wondered what might account for this discrepancy. One possibility is that we only obtained BRIEF ratings from parents, when in fact the questionnaire is designed to be completed
independently by both parents and teachers. It is possible that parents may focus more on behavioural issues and less on the sorts of higher-level planning and problem solving that might be more apparent in a school environment, for example following a timetable. Parents are likely to do a lot of the day-to-day organising on behalf of their child, as this simply gets things done. Therefore higher-level difficulties might be more readily assessed in an environment where the child is expected to be more independent, such as school. Investigations using both parent and teacher questionnaires would be necessary to explore this possibility.

We investigated relationships between BRIEF sub scores and multitask variables hoping to provide further support for the ecological validity of our paradigm. The results of this correlative analysis show that some BRIEF sub scale scores did correlate with multitasking variables, thereby supporting the validity of the multitask paradigm as a test that taps into organisation difficulties in everyday life. As a note of caution, the correlations we report are all significant at an alpha level = .05. We are aware that we performed multiple comparisons with a very small number of participants, hence these relationships remain speculative at this time.

The BRIEF initiate score correlated with multitask performance, switching and recount. Initiate measures the ability to begin tasks independently and to generate thoughts and ideas. The ability to begin tasks independently could relate to the requirement to begin many tasks during multitask performance and to switch between them fluently. The correlation between BRIEF initiate and recount had not been anticipated. It is possible that generating thoughts and ideas is a metacognitive skill, as is the ability to monitor one's behaviour. Multitask switching also correlated with the BRIEF working memory sub scale; this relationship can be explained as holding in mind the intention to switch between multiple tasks and the ability to successfully execute this intention rely upon working memory capacity. Similarly, Siklos and Kerns (2004) reported a correlation between task switching on their multitask and an independent measure of working memory. BRIEF working memory also correlated with multitask rule learning. It is likely that working memory was employed to learn the rules of the paradigm which were then transferred to long term memory, as no relationship between rule memory and working memory emerged. Unexpected relationships were observed between multitask rule learning and memory scores and the BRIEF inhibit sub scale. It is not entirely clear why inhibitory
control is related to participants' ability to learn and remember the rules of the multitask paradigm and it would be interesting to investigate whether this relationship would also be apparent between control participants. Likewise, multitask rule memory is related to BRIEF shift sub scale, which measures cognitive flexibility. A degree of mental flexibility may be necessary to interpret the rules of the paradigm, although we had expected the shift sub scale to be more related to the flexible application of these rules, as measured by the multitask task switch variable. However, no significant correlation between shift and switch was found.

In fact, a number of relationships we had anticipated were not observed. The multitask switch variable was expected to correlate with the BRIEF inhibit and shift sub scales, this was because in models of prospective memory, task switching relies upon inhibiting attention to the current activity enabling a shift of attention to the prospective activity (Kliegel et al., 2000). Likewise, we had expected the multitask recount measure to correlate with the BRIEF monitor sub scale, as these measures both concern the ability to keep track of goal-directed behaviour; however no relationship was found. Finally, planning on the multitask paradigm and the BRIEF plan/organise sub scale failed to show any relationship. It is difficult to account for these non-significant relationships, given that many of these variables are conceptually similar. It remains entirely possible that task switching impairments in ASD are attributable to inhibition and/or cognitive flexibility and this relationship should be explored in the ways we discussed above. It is possible that in its present form the recount score in our paradigm does not properly assess the performance monitoring skills. Although planning deficits were reported in the multitask paradigm and planning difficulties were apparent in the elevated scores on the BRIEF plan/organise sub scale, no relationship between these evident planning impairments was observed. Many questions on the BRIEF plan/organise sub scale refer to planning ahead towards a single goal. As discussed previously planning in the multitask paradigm involves planning in more complex, less clearly defined situations.

In sum, children who are impaired on the multitask also have difficulty organising everyday activities. A number of relationships between variables on the multitask test and sub scales on the BRIEF questionnaire have been observed. For the most part these results add to the ecological validity of multitasking as a test of real life organisational difficulties. Further they contribute to the growing
practice in autism research of linking performance on experimental paradigms to ratings of behaviour in everyday life (e.g., Dawson et al., 2002; Hughes, 2001; Joseph & Tager-Flusberg, 2004; Ozonoff et al., 2004). The Battersea Multitask Paradigm is designed to tap the cognitive processes underlying the organisation of future-oriented behaviours. Whilst many of the questions in the BRIEF address the prospective organisation of actions (for example, 'forgets to hand in homework, even when completed'), these questions are scattered over many sub scales of the BRIEF. Therefore, no individual sub scale links specifically to the prospective organisation of actions. In future a questionnaire aimed at measuring prospective memory difficulties in ASD may prove illuminating in addition to one only measuring executive function difficulties.

9.6 Summary of limitations and recommendations for future studies

Throughout this discussion we have mentioned specific limitations of this study and these are summarised here. (1) The response rates for both the TD control group and the HF-ASD group were fairly low and it is possible that this biased the sample towards children who did or did not have everyday organisational difficulties. (2) Not all data was collected at the time the multitask study was performed. (3) Verbal fluency may influence planning scores and no independent measure of verbal fluency was obtained. (4) BRIEF data were only collected from parents of children in the clinical group; teacher ratings and data from the control group would have been desirable. Clearly it would be of benefit to investigate multitasking in children with HF-ASD in a large study designed to surmount these limitations.

We plan to investigate whether we can identify sub groups of children within our existing data set. This would enable us to assess whether children who performed poorly on the multitask also had higher BRIEF scores and/or lower IQ's. A preliminary look at the data indicated that the number of children involved in any sub group analyses is likely to be small, and that the pattern of relationships between variables is not very clear. A further benefit of having a larger sample would be to explore more sizeable sub groups of participants.
Furthermore, our data have raised important questions about what underlies the multitasking deficit observed in children with HF-ASD. In future studies it would be beneficial to use independent measures of the cognitive processes hypothesised to be involved in the prospective organisation of action alongside the multitask paradigm, for example, measures of verbal fluency, planning, cognitive flexibility and prospective memory. Comparisons between different clinical groups may prove fruitful, and we have discussed the attractive possibility of a different profile of multitasking difficulties in children with HF-ASD versus children with ADHD. This hypothesis awaits further investigation in a single study. Within-task manipulations of the cognitive processes supporting multitasking should also be explored as a promising way of assessing the cognitive processes underlying multitasking. This research would not only enhance our understanding of the everyday organisation difficulties experienced by children with developmental disorders, but would also inform the theoretical basis of the development of these abilities in childhood.

9.7 Chapter summary

In this study we have demonstrated multitasking deficits in children with HF-ASD relative to age, gender and IQ matched controls, replicating and extending previous research. We interpret these results as experimental evidence that children with HF-ASD have problems in the prospective organisation of actions. We supported this interpretation with evidence from a parent report measure which shows that children with HF-ASD both perform poorly on our multitask paradigm and have difficulties organising future-oriented activities in their everyday lives. Finally, children’s performance on some multitask variables correlated with parent ratings of everyday organisational difficulties; this finding supports the ecological validity of multitasking.
In previous chapters we have presented data on multitasking in children aged 6 to 14-years as well as young adults. In each of these studies we have reported developmental differences between the age groups investigated. This chapter provides the opportunity to draw together data from these previous studies to map the developmental trajectories of multitask variables and look at the relationships between these variables. This chapter has four main aims:

1. **Select a sample**: we set inclusion criteria and specify the age cohorts of participants who will be included in this chapter. We also introduce some new participants to the sample.

2. **Map developmental trajectories**: we plot developmental trajectories of variables generated by the multitask paradigm. We highlight where patterns differ between variables across age groups, and make some observations about how the contributions of cognitive skills underlying multitasking may vary across development.

3. **Consider the cognitive processes underlying multitasking**: following Burgess et al., (2000) we investigate patterns of correlation between the key variables generated by multitasking. We ask whether the patterns of correlation in our data set support the notion that retrospective memory, planning and prospective memory are independent cognitive processes underlying multitasking. We investigate the developmental trajectories of each of these underlying cognitive processes.

4. **Summarise and discuss**: we discuss the results and consider the development of the cognitive processes supporting multitasking.
10.1 Select a sample

10.1.1 Total available sample

In previous chapters we reported data from children of various ages and young adults. These data and the relevant chapter numbers are summarised in Table 10.1. In the present chapter we added more participants to the 12-year old and the adult groups; these extra participants are also detailed in Table 10.1. The additional 12-year old participants are 6 girls who were initially assessed as controls in the clinical study reported in Chapter 9, but subsequently excluded when we confined our control group to boys only, to match our clinical sample. These 12-year old girls were recruited by the procedure outlined in Chapter 9. Adding them to the 12-year old sample results in a new group size of 22. Additional adult participants were recruited to form a larger adult group to compare to the various sizes of children’s groups. These adults were recruited by an email circulated in our research institution in which we requested people to give up 15 minutes of their time to participate in our study. Eighteen individuals responded to the email, all of whom were assessed by a summer placement student who had been trained to administer the multitask paradigm. Testing took place in a quiet room; the administration procedure was identical to that outlined in Chapter 6 and each test session was videotaped. Performance was scored by the Ph.D. candidate using on-line record sheets and video footage. Table 10.1 details the total numbers of participants in each age group available to select from in this chapter.

**Table 10-1: All participants available to select from in this chapter**

<table>
<thead>
<tr>
<th>Chapter</th>
<th>6-years</th>
<th>8-years</th>
<th>10-years</th>
<th>12-years</th>
<th>14-years</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original multitask (5)</td>
<td>38</td>
<td>35</td>
<td>35</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Training study (6)</td>
<td>18</td>
<td>21</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14 &amp; Adult study (8)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>21</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Clinical study controls (9)</td>
<td>-</td>
<td>-</td>
<td>16</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Additional participants (10)</td>
<td>6</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Available participants</td>
<td>56</td>
<td>56</td>
<td>35</td>
<td>22</td>
<td>21</td>
<td>52</td>
</tr>
</tbody>
</table>
10.1.2 Setting inclusion criteria

As in previous chapters, the inclusion criteria in this chapter relate to rule learning. A potential caveat must be addressed. Although all the participants featured in Table 10.1 performed the same multitask paradigm, two slightly different administration procedures were employed. Specifically, some children were trained to be able to repeat the four rules of the paradigm prior to performing it, whilst others were not. Rule trained children include some 6-year (N=18), some 8-year (N=21) and all 12-year old children (N=22). This training procedure was carried out with 6 and 8-year old children because the 6-year olds in our original multitask study (Chapter 5) were significantly poorer at learning the rules of the paradigm, and we wanted to assess whether this impacted upon their multitask performance (it did not). The rule training procedure was also adopted with the 12-year old children who acted as a control group to clinical participants (Chapter 9). This was done in order to ensure that clinical participants learned the rules to the same level as controls. The issue is whether this difference in administration curtails meaningful comparisons across these studies. We believe it need not, if satisfactory inclusion criteria are adopted.

The purpose of the rule training procedure was to ensure that 6-year old and clinical participants had adequate knowledge of what they were being asked to do during the multitask paradigm. The key test of a participant's knowledge of these rules is not in their ability to repeat them by rote, but in their ability to answer a series of questions testing their knowledge of the rules. The impact of rule training, therefore, ensured that participants were better able to answer these questions. Following this line of reasoning, the inclusion criteria for this chapter are that participants must obtain a minimum threshold score of 7/10 for their answers to questions about the rules and parameters of the multitask paradigm. Furthermore, they must have correctly answered the 4 questions directly pertaining to the 4 rules of the paradigm. This method of assessing rule knowledge follows that of Burgess et al., (2000) who measured rule knowledge by scoring participants' answers to cued knowledge questions. The cued questions and the points awarded for them in our Battersea multitask are detailed in Table 10.2.
Table 10-2: Cued rule learning questions and points awarded for correct answers

<table>
<thead>
<tr>
<th>Cued knowledge question</th>
<th>Correct answer (points awarded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>How many games are there? (3)</td>
<td>3 (1 point)</td>
</tr>
<tr>
<td>** What is special about yellow things?</td>
<td>More points (1 point)</td>
</tr>
<tr>
<td></td>
<td>More points than blue (2 points)</td>
</tr>
<tr>
<td>** How many of the games should you try?</td>
<td>All/ 3 (1 point)</td>
</tr>
<tr>
<td>How long do you have to play the games?</td>
<td>3 minutes/ until the sand/ when the time runs out (1 point)</td>
</tr>
<tr>
<td>Do you think you could finish all of the games before the sand runs out?</td>
<td>No (1 point)</td>
</tr>
<tr>
<td>When does the game stop?</td>
<td>After 3 mins./ when the sand/ when time runs out (1 point)</td>
</tr>
<tr>
<td>** Can you have more than one thing in your hand?</td>
<td>No (1 point)</td>
</tr>
<tr>
<td>Why should you go as quickly as you can?</td>
<td>Get lots of points/ before time runs out/ fill things up (1 point)</td>
</tr>
<tr>
<td>** Why should you try to fill up squares and caterpillars and pots?</td>
<td>To get lots of/ extra/ bonus points (1 point)</td>
</tr>
</tbody>
</table>

**Total Score** | **Ranges from 0 to 10 points**

**Questions relating directly to the 4 rules of the paradigm: these must be answered correctly for participants to be included in the analyses in this chapter, in addition to which participants must score 7/10 overall.

The majority of participants in each age group met these inclusion criteria, these participants are summarised in Table 10.3. Sixteen 6-year olds and five 8-year olds failed to meet rule learning criteria. The 6-year olds were all from the sample reported in Chapter 5, and had not been trained to learn the rules of the multitask paradigm. They were 8 boys and 8 girls, each of whom answered only 2-3 of the 4 key questions about the rules of the game. Their mean cued rule knowledge score was 6.56 (SD = 1.03), with a range of 4-8 out of 10 points scored. The 8-year old participants who failed to meet inclusion criteria were from the 8-year old sample reported in Chapter 5, and had also not been trained to learn the rules of the multitask paradigm. They were 2 boys and 3 girls; their mean cued rule knowledge score was 8.40 (SD = 0.89), with a range of 7-9 out of 10 points scored. Each child in this group answered 3 of the 4 key questions correctly. All children who failed to meet inclusion criteria are excluded from further analyses here.
Table 10-3: All participants from multitask meeting inclusion criteria for this chapter

<table>
<thead>
<tr>
<th>Number of participants in each age group</th>
<th>6-years</th>
<th>8-years</th>
<th>10-years</th>
<th>12-years</th>
<th>14-years</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available participants</td>
<td>56</td>
<td>56</td>
<td>35</td>
<td>22</td>
<td>21</td>
<td>52</td>
</tr>
<tr>
<td>Excluded participants</td>
<td>16</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Included participants</td>
<td>40</td>
<td>51</td>
<td>35</td>
<td>22</td>
<td>21</td>
<td>52</td>
</tr>
</tbody>
</table>

Having identified all the participants who are eligible to be included in the analyses in this chapter, we now turn our attention to defining the age groups to be used in these analyses.

10.1.3 Defining age groups

To investigate developmental trajectories in multitasking, we wanted to compare performance across different age groups of participants. Thus far, we have been referring to children in the age groups they were recruited into. The box plots in Figure 10.1 illustrate the mean age and range of age in months for children in each age group: 6, 8, 10, 12 and 14-years.

Figure 10-1: Box plots for age in months of each age group (children)
Examination of Figure 10.1 shows that whilst the majority of age groups are clearly independent from other groups in terms of age in months, there is considerable overlap between the 10 and 12-year old age groups. Further, two outliers are identified in the 12 and 14-year old groups.

The 6-year old group ranges in age from 66-80 months. The 8-year old group ranges in age from 90-104 months. These age ranges do not overlap. However, the range of ages of the 10 and 12-year old groups overlap: 10-year-olds range 122-134 months, 12-year olds range 130-151 months. To eliminate this overlap, we set limits on the age range within each group and excluded children whose age fell outside of these limits. Our 10-year old group was recruited and assessed late in the school year, with the result that their mean age was 10 years and 6 months (126 months). We set a limit of 6 months on either side of this mid-point giving a range of 120-132 months. The 12-year-olds were recruited as age matched controls for the group with HD-ASD and their age range was broader to match that of the clinical group. Their mean age was 144 months (exactly 12 years); 6 month limits on either side of this mid point gives a range of 138-150 months. With these limits the range of ages for the 10 and 12-year old groups no longer overlap, but are 6 months apart at their closest point. In total 29 children of the original thirty-five 10-year olds fall inside this age range, plus another 2 children who were originally recruited into the 12-year old group, resulting in a group of 31 children aged 10-years old. Nineteen children fall within the age limits set for the 12-year old group: of the original 22 children, 2 were moved to the 10-year group, and 1 child was only 135 months old, hence too young for inclusion. The box plot of the 14-year old group indicates the presence of an outlier, a child who is only 13 rather than 14 years old (156 months). With this child excluded from the group, the remaining 20 children fit into a clearly defined age range, of 163-173 months, 5 months either side of 14-years (168 months).

The range of ages in our adult group was far wider than that of our children's groups: 249-609 months (see Figure 10.2). Three clear outliers representing adult participants who were older than the majority of the group were removed from subsequent analyses (509, 529 & 629 months), leaving 49 adults, ranging from 20-38 years of age (249-456 months).
10.1.4 Characteristics of the final sample

More closely defining the age limits of our groups has resulted in some cases being lost from the overall sample we had available to choose from, although we are left with reasonably sized groups of participants. Descriptive data for the final age groups are summarised in Table 10.4 below. These groups will be used in the analyses in this chapter.

<table>
<thead>
<tr>
<th>Variable</th>
<th>6-yrs</th>
<th>8-yrs</th>
<th>10-yrs</th>
<th>12-yrs</th>
<th>14-yrs</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (SD)</td>
<td>6.15 (3.68)</td>
<td>8.06 (3.65)</td>
<td>10.63 (3.25)</td>
<td>12.04 (3.80)</td>
<td>14.05 (2.86)</td>
<td>27.23 (49.23)</td>
</tr>
<tr>
<td>Range</td>
<td>66-80</td>
<td>90-104</td>
<td>122-132</td>
<td>139-150</td>
<td>163-173</td>
<td>249-456</td>
</tr>
<tr>
<td>Sex m, f</td>
<td>23m, 17f</td>
<td>27m, 24f</td>
<td>16m, 15f</td>
<td>13m, 6f</td>
<td>8m, 12f</td>
<td>20m, 29f</td>
</tr>
<tr>
<td>Total N</td>
<td>40</td>
<td>51</td>
<td>31</td>
<td>19</td>
<td>20</td>
<td>49</td>
</tr>
</tbody>
</table>

Ethnicity: the majority of participants were Caucasian (80%), but each group contained participants from a variety of ethnic origins, reflecting the multicultural population from which they were sampled. The exception to this was the 14-year-old group, recruited outside of London from a less culturally diverse area. The distribution was as follows: 6-year olds: 31 Caucasian, 5 Afro Caribbean, 2 Asian, 1
Chapter 10: Developmental trajectories in multitasking

Chinese and 1 child mixed race; 8-year olds: 40 Caucasian, 6 Afro Caribbean, 2 Asian, 1 Chinese and 2 mixed race; 10-year olds: 17 Caucasian, 9 Afro Caribbean, 4 Asian and 1 mixed race; 12-year olds: 15 Caucasian, 2 Afro Caribbean and 2 Asian; 14-year olds: 19 Caucasian and 1 Asian child; adults: 43 Caucasian, 1 Afro Caribbean, 3 Asian, 1 Chinese and 1 mixed race.

We had obtained IQ estimates for the majority of participants in the sample and these are detailed in Table 10.5 below. The verbal IQ estimate represents standard scores on the vocabulary sub-test of the Weschler Intelligence Scales for adults and children (WAIS-R\textsuperscript{UK} for adults and WISC-III\textsuperscript{UK} for children). The exception is the 12-year old group who performed the similarities sub-test instead, this was because they did a WISC-III\textsuperscript{UK} short form of four sub tests whilst acting as controls to the HF-ASD group. The non-verbal IQ estimate represents standard scores on the block design sub-test. IQ standard scores have a mean of 10 and a standard deviation of 1.5.

<table>
<thead>
<tr>
<th>IQ Estimate</th>
<th>Age group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6-yrs</td>
</tr>
<tr>
<td>Verbal</td>
<td>9.68 (3.70)</td>
</tr>
<tr>
<td>Non Verbal</td>
<td>10.00 (2.74)</td>
</tr>
<tr>
<td>Total N</td>
<td>22</td>
</tr>
</tbody>
</table>

The majority of age groups are broadly comparable in terms of IQ. However, the 14-year old group stands out as being of below average intelligence, and the 34 adults assessed obtained higher standard scores than children. One way between groups analyses of variance indicate that groups scored significantly differently from one another for each of these IQ estimates: verbal IQ, F (5, 150) = 10.98, p < .001; and non-verbal IQ, F (5, 150) = 8.47, p < .00. Post hoc analyses reveal that the adult group is significantly different to all other age groups for both IQ scores (Tukey HSD p < .01), but that the 14-year old group does not differ significantly from other groups of children. Adults recruited from business and academic environments are likely to be of high average intelligence. Therefore, when we use this adult sample as a comparison group we should consider the impact this difference in ability may have upon our results.
10.2 Map developmental trajectories

In previous chapters we have reported age-related differences in multitasking between participants belonging to various age groups. Having identified participants from all these different age groups who meet inclusion criteria for this chapter, we now draw together these samples to examine multitasking in six age cohorts of participants. In this section we discuss group performance on the key variables generated by multitasking and plot the developmental trajectories of these variables across the 6-year to adult age range. We investigate how scores on these variables differ across age groups, and how this pattern of development compares between key variables. In addition, the composite multitask performance score is broken down into its component scores, and different developmental trajectories for each of these scores are discussed. The data are presented as follows:

**Key Multitask Variables**
1. Means and standard deviations for all key variables - Table 10.6
2. Mann Whitney U tests for group comparisons on all key variables – Table 10.7
3. Graphs of means and standard deviations for all key variables - Figure 10.3 (a)-(f)
4. z score plots of some key variables - Figure 10.4 (a)-(c)
5. Discussion of these data

**Multitask Performance Variables**
1. z score plots of multitask performance variables - Figure 10.5 (a)-(c)
2. Mann Whitney U tests for group comparisons on multitask performance variables – Table 10.8
3. Discussion of these data
10.2.1 Key multitask variables

[1] Age group means and standard deviations for all key variables

The data are too heterogeneous to permit parametric statistical analyses (Levene’s test), therefore group differences on all key variables are investigated using the Kruskal-Wallis non-parametric statistic. The results of this test are detailed in the last row of Table 10.6.

Table 10-6: Age group scores on key multitask variables

<table>
<thead>
<tr>
<th>Age Group (N)</th>
<th>Learn (max 10)</th>
<th>Memory (max 10)</th>
<th>Plan (max 12)</th>
<th>Follow (max 12)</th>
<th>Perform (max 20)</th>
<th>Recount (max 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 (40)</td>
<td>8.72 (0.98)</td>
<td>8.97 (1.01)</td>
<td>7.40 (3.14)</td>
<td>5.55 (2.88)</td>
<td>9.45 (5.35)</td>
<td>6.97 (2.24)</td>
</tr>
<tr>
<td>8 (51)</td>
<td>9.33 (0.68)</td>
<td>9.43 (0.67)</td>
<td>7.33 (2.74)</td>
<td>6.58 (2.49)</td>
<td>12.56 (4.57)</td>
<td>8.00 (1.64)</td>
</tr>
<tr>
<td>10 (31)</td>
<td>9.25 (0.85)</td>
<td>9.38 (0.49)</td>
<td>9.22 (2.52)</td>
<td>8.58 (2.79)</td>
<td>14.87 (5.12)</td>
<td>8.12 (1.58)</td>
</tr>
<tr>
<td>12 (19)</td>
<td>9.47 (0.61)</td>
<td>9.52 (0.51)</td>
<td>10.68 (1.49)</td>
<td>9.78 (1.18)</td>
<td>15.57 (3.65)</td>
<td>9.00 (0.00)</td>
</tr>
<tr>
<td>14 (20)</td>
<td>9.15 (0.48)</td>
<td>9.30 (0.47)</td>
<td>10.50 (1.43)</td>
<td>10.10 (1.48)</td>
<td>16.30 (2.47)</td>
<td>8.75 (0.78)</td>
</tr>
<tr>
<td>Adult (49)</td>
<td>9.30 (0.46)</td>
<td>9.24 (0.48)</td>
<td>10.73 (2.19)</td>
<td>10.40 (2.15)</td>
<td>17.89 (1.67)</td>
<td>8.93 (0.42)</td>
</tr>
</tbody>
</table>

Kruskal-Wallis (p): \( \chi^2(5) = 16.21 \) (p < .01) for Learn, \( \chi^2(5) = 10.04 \) (NS) for Memory, \( \chi^2(5) = 58.36 \) (p < .001) for Plan, \( \chi^2(5) = 85.16 \) (p < .001) for Follow, \( \chi^2(5) = 74.50 \) (p < .001) for Perform, and \( \chi^2(5) = 70.81 \) (p < .001) for Recount.
Mann Whitney U tests for group comparisons on all key variables

The Kruskal-Wallis tests reported in Table 10.6 indicate that there are significant group differences for all other multitask variables. We calculated Mann Whitney U tests for each age group in comparison to all other age groups to investigate where these significant differences lie. These results are reported in Table 10.7 below.

Table 10-7: Mann-Whitney U test results for key multitask variables

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Learn</th>
<th>Memory</th>
<th>Plan</th>
<th>Plan Follow</th>
<th>Perform</th>
<th>Recount</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 v 8</td>
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<td>z = -2.23*</td>
<td>z = -0.16</td>
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<td>z = -2.87**</td>
<td>z = -2.30*</td>
</tr>
<tr>
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<td>z = -1.59</td>
<td>z = -2.41*</td>
<td>z = -3.92***</td>
<td>z = -3.96***</td>
<td>z = -2.41*</td>
</tr>
<tr>
<td>6 v 12</td>
<td>z = -2.81**</td>
<td>z = -2.07*</td>
<td>z = -3.76***</td>
<td>z = -5.12***</td>
<td>z = -3.97***</td>
<td>z = -3.91***</td>
</tr>
<tr>
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<td>z = -0.92</td>
<td>z = -3.74***</td>
<td>z = -5.31***</td>
<td>z = -4.68***</td>
<td>z = -3.34**</td>
</tr>
<tr>
<td>6 v Adult</td>
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<td>z = -0.86</td>
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<td>z = -6.51***</td>
<td>z = -7.05***</td>
<td>z = -5.58***</td>
</tr>
<tr>
<td>8 v 10</td>
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<td>z = -0.71</td>
<td>z = -2.81***</td>
<td>z = -3.11**</td>
<td>z = -2.37*</td>
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</tr>
<tr>
<td>8 v 12</td>
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<td>z = -4.51***</td>
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<td>z = -3.38***</td>
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</tr>
<tr>
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<td>z = -1.76</td>
<td>z = -0.03</td>
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</tr>
<tr>
<td>10 v 14</td>
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<td>z = -0.63</td>
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<td>z = -2.13*</td>
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<tr>
<td>12 v Adult</td>
<td>z = -1.38</td>
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<td>z = -0.92</td>
<td>z = -2.22*</td>
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<td>z = -0.62</td>
</tr>
<tr>
<td>14 v Adult</td>
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<td>z = -1.33</td>
<td>z = -1.27</td>
<td>z = -2.61**</td>
<td>z = -1.44</td>
</tr>
</tbody>
</table>

*** p < .001, ** p < .01, * p < .05.
Chapter 10: Developmental trajectories in multitasking

[3] Graphs of means and standard deviations for all key variables

The mean scores for each age group (plus and minus 1 standard deviation) are plotted for the six key variables in Figure 10.3.

Figure 10-3: Age group scores on key multitask variables

(a) Cued Rule Learning

(b) Cued Rule Memory

Error Bars show Mean +/- 1.0 SD
Figure 10-3: Age group scores on key multitask variables (continued)
Chapter 10: Developmental trajectories in multitasking

[4] z score plots of some key multitask variables

We converted some key multitask scores to standardised z scores (using the formula described in Chapter 6) and plotted the developmental trajectories of these variables. Rule learning/memory are excluded as they were designed to be equal across age groups.

Figure 10-4: z scores for Plan and Plan Follow, Multitask Performance and Recount
Discussion of key multitask variables

Mean rule learning scores and standard deviations for each age group are detailed in Table 10.6. The results of the Kruskal-Wallis test confirm that rule learning is not at the same level in all age groups: $\chi^2 (5) = 16.21; p < .01$. Group differences in rule learning are detailed in Table 10.7. The Mann Whitney U tests indicate that 6-year olds obtain significantly lower scores than most other age groups. Group scores for rule learning are presented in Figure 10.3(a); the pattern of results illustrates that 6-year olds obtain lower scores than participants in all other age groups, and that there is greater variation in the scores obtained by younger participants than those obtained by older participants. Recall that participants must be able to answer the four cued questions directly relating to the rules of the paradigm, and to obtain a minimum score of 7/10 points for answers to all cued questions in order to be included in these analyses. This means that all 6-year olds have passed a meaningful threshold for rule learning. The group difference arises because their responses to other cued questions were less effective, resulting in their rule learning scores being poorer than those of the other participant groups.

A similar pattern of result emerges for rule memory, the means in Table 10.6 indicate that 6-year olds may remember fewer rules than participants in other groups, however this fails to reach statistical significance, Kruskal-Wallis $\chi^2 (5) = 10.04; p = .074$. Group differences in rule memory are detailed in Table 10.7. Mann Whitney U tests indicate that 6-year olds remember significantly fewer rules than some, but not all, other age groups. Eight and 12-year olds also remember fewer rules than adults. The pattern of rule memory scores is illustrated in Figure 10.3(b), and confirms this lack of overall group differences. As all participants passed a threshold for rule learning and no significant group differences were observed for rule memory, we can be fairly confident that participants in all age groups had a good idea of what they were supposed to be doing when performing the multitask paradigm. Having demonstrated that the groups are broadly equal in their ability to learn and retain information about the multitask paradigm, we shall not focus further on rule learning and memory. Instead, we proceed to investigate developmental trajectories in other aspects of multitasking.

Age group means and standard deviations for plan and plan follow are illustrated in Figure 10.3(c) and (d), and Table 10.6. The groups do not plan at the same level: Kruskal-Wallis $\chi^2 (5) = 58.36; p < .001$. The Mann Whitney U tests in Table 10.7 indicate that the key differences in planning scores are between 6 and 8-year olds and all other participants. The pattern of scores in Figure 10.6(c) supports
this pattern of results. The developmental trajectory for planning in multitasking is one in which 6 and 8-year olds plan at an equivalent level, followed by rapid improvement between 8, 10 and 12-years, at which point planning scores approach ceiling with no further increments observed beyond 12-years of age. The pattern of results for plan following is different; developmental increments occur across all age groups resulting in a continual upward trajectory, as illustrated in Figure 10.3(d). A Kruskal-Wallis test presented in Table 10.6 confirms that the groups are significantly different from one another in terms of plan following: $\chi^2 (5) = 85.16; p < .001$. The results of the Mann Whitney U tests in Table 10.7 indicate that 6, 8 and 10-year olds are significantly different to almost all other groups on the plan following score and 12, but not 14-year olds, are different to adults.

In order to compare the trajectories of planning and plan following on an equivalent scale, raw scores were converted to z scores and plotted in Figure 10.4(a). The z score trajectories match those of the raw scores discussed above. Planning is equivalent between 6 and 8 years, and develops from 8 to 12 years at which point an adult level of planning is accomplished. Plan following shows a pattern of continual development from 6 years into young adulthood. By comparing one line in Figure 10.4(a) to the other, we can assess where participants failed to implement the plan they have made. Six-year olds plan at an equivalent level to 8-year olds, but fail to follow this plan through. Participants in all other age groups successfully implement their plans, as the plan following score does not fall below the planning score.

How well participants perform the multitask paradigm is measured by the composite multitask performance score, the means and standard deviations for which are detailed in Table 10.6 and Figure 10.3(e). The pattern of results indicates that multitask performance improves across all participant groups, with performance increments between all age groups. The pattern of decreasing variance in multitask performance (smaller standard deviations) with increasing age is also striking, indicating that the performance of older participants is more consistent that the performance of younger participants. A Kruskal-Wallis test confirms that the groups perform differently $\chi^2 (5) = 74.50; p < .001$. Group differences tested by Mann Whitney U tests are presented in Table 10.7 and support this pattern of developmental differences. Six and 8-year old children perform significantly differently to all other age groups. Ten to 14-year old children do not perform significantly differently from one another, but
their performance is different to that of adults. The mean z scores presented in Figure 10.4(b) clearly illustrate the ongoing developmental trajectory of multitask performance. As we discussed previously, multitask performance is a composite score representing task switching, strategic rule use and error making/ rule breaking scores. In the next section we consider age group performance on each of these aspects of performance to identify what contributes to this overall developmental trajectory.

All participants scored well on the recount variable, with participants above 10-years of age scoring at ceiling (see means in Table 10.6). The scoring system we designed was based on the recounting abilities of our youngest participants. And, as such, older children and adults tend to be at ceiling on this measure. A Kruskal-Wallis test confirms that the recount scores are significantly different between age groups: $\chi^2 (5) = 70.81; p < .001$. The Mann Whitney U tests presented in Table 10.7 indicate that these differences are primarily between the 6 to 10-year old children compared to all other groups. Using this rather simple measure of recounting demonstrates some developmental differences across middle childhood, but the ceiling effects preclude us from making further judgements about the continued development of this skill through late childhood and adolescence into adulthood. The developmental trajectory of scores on the recount measure is detailed as mean scores in Figure 10.3(f) and as z scores in Figure 10.4(c).

In sum, the data presented above give the overall impression of age-related differences in multitasking. The trajectories plotted in Figure 10.4 illustrate a pattern of incremental change with increasing age for planning, plan following and multitask performance. Two variables show an exception to this pattern: rule learning and rule memory scores which were manipulated to be at ceiling.
10.2.2 Multitask performance variables

Multitask performance is a composite score comprising task switching, strategic rule use and error making/ rule breaking scores. Figure 10.5 details the developmental trajectories of each of these underlying scores presented as z scores (error bars show mean +/- 1SD).

Figure 10-5: z scores for task switching, strategic rule use and error making/ rule breaking
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[2] Mann Whitney U tests for group comparisons on performance variables
To investigate the presence of group differences for multitask performance variables, Mann Whitney U tests were calculated for group differences between all age groups for strategic rule use, error making and rule breaking scores. As described in previous chapters, participants task switch performance was determined as inefficient or efficient. Group differences in task switching were investigated using group by group \( X^2 \) tests. These results are summarised in Table 10.8.

Table 10-8: Mann-Whitney U tests for performance variables and \( X^2 \) comparisons for switching

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Strategic</th>
<th>Errors</th>
<th>Rule Break</th>
<th>Rule Break</th>
<th>Switch</th>
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<tr>
<td></td>
<td>(N Participants in each group who broke the rules)</td>
<td>(Frequency of rule breaks in each group)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 v 8</td>
<td>( z = -2.86^{**} )</td>
<td>( z = -1.39 )</td>
<td>( z = -0.10 )</td>
<td>( z = -0.08 )</td>
<td>( X^2 = 4.08^* )</td>
</tr>
<tr>
<td>6 v 10</td>
<td>( z = -3.74^{***} )</td>
<td>( z = -1.38 )</td>
<td>( z = -0.44 )</td>
<td>( z = -0.41 )</td>
<td>( X^2 = 13.22^{***} )</td>
</tr>
<tr>
<td>6 v 12</td>
<td>( z = -3.76^{***} )</td>
<td>( z = -1.27 )</td>
<td>( z = -1.71 )</td>
<td>( z = -1.78 )</td>
<td>( X^2 = 8.84^{**} )</td>
</tr>
<tr>
<td>6 v 14</td>
<td>( z = -4.56^{***} )</td>
<td>( z = -1.97^* )</td>
<td>( z = -1.36 )</td>
<td>( z = -1.51 )</td>
<td>( X^2 = 9.64^{**} )</td>
</tr>
<tr>
<td>6 v Adult</td>
<td>( z = -6.96^{***} )</td>
<td>( z = -2.08^* )</td>
<td>( z = -0.55 )</td>
<td>( z = -0.74 )</td>
<td>( X^2 = 35.56^{***} )</td>
</tr>
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<td>8 v 10</td>
<td>( z = -2.07^* )</td>
<td>( z = -0.23 )</td>
<td>( z = -0.34 )</td>
<td>( z = -0.23 )</td>
<td>( X^2 = 4.15^* )</td>
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<td>( X^2 = 2.44 )</td>
</tr>
<tr>
<td>8 v 14</td>
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<td>( z = -1.28 )</td>
<td>( z = -1.40 )</td>
<td>( z = -1.49 )</td>
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<tr>
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<td>( z = -0.69 )</td>
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<td>( z = -1.93 )</td>
<td>( X^2 = 0.02 )</td>
</tr>
<tr>
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<td>( z = -0.55 )</td>
<td>( z = -1.15 )</td>
<td>( z = -1.58 )</td>
<td>( z = -1.74 )</td>
<td>( X^2 = 0.00 )</td>
</tr>
<tr>
<td>10 v Adult</td>
<td>( z = -2.59^* )</td>
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<td>( z = -0.95 )</td>
<td>( z = -1.11 )</td>
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<tr>
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<td>( z = -1.03 )</td>
<td>( z = -0.39 )</td>
<td>( z = -0.36 )</td>
<td>( X^2 = 0.01 )</td>
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<tr>
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<td>( z = -3.00^{**} )</td>
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<td>( z = -0.98 )</td>
<td>( z = -1.06 )</td>
<td>( X^2 = 4.53^* )</td>
</tr>
</tbody>
</table>

*** \( p < .001 \), ** \( p < .01 \), * \( p < .05 \)
Chapter 10: Developmental trajectories in multitasking

[3] Discussion of multitask performance variables

The pattern of results for the performance scores illustrated in Figure 10.5 is one of greater variability in the performance of younger children. Scores on the switch performance variable, Figure 10.5(a), illustrate how participants' ability to switch between tasks changes across the age groups. Inefficient switching involves perseverating on a few tasks or switching too rapidly between tasks; efficient switching reflects fluent and strategic movement between tasks. Significant gains in switching are made between 6, 8 and 10-years of age, with a plateau in this skill evident in children aged 10-14 years and a further increment occurring between 14-years of age and adulthood. This trajectory differs from the steadily increasing trajectory of the composite multitask performance score. The percentage of participants in each group who selected an efficient switch strategy are: 6-years (37.5%), 8-years (58.82%), 10-years (80.65%), 12-years (78.95%), 14-years (80.00%) and adult (95.92%). The groups differ significantly from one another for task switching: Kruskal-Wallis $\chi^2 (5) = 42.34$; $p < .001$. The results of the tests presented in Table 10.8 confirm the pattern described above. Significant differences in switching were observed between 6 and 8-year old children and all other age groups, whilst 10, 12 and 14-year olds did not switch differently from one another but did switch differently from adults. The vast majority of participants who switched inefficiently demonstrated perseverative behaviour and failed to switch often enough, with only two 6-year olds and one 12-year old switching too rapidly between tasks. This perseveration was marked in younger children in the sample, resulting in 30% of 6-year olds (N=12), 11.7% of 8-year olds (N=6) and 9.7% (N=3) of 10-year olds failing to attempt all three tasks. All 12, 14-year old and adult participants successfully attempted all three tasks.

In addition to switching, we measure how well participants use the rules of the multitask paradigm to obtain points: this score is referred to as strategic rule use. The developmental trajectory for strategic rule use is plotted in Figure 10.5(b). Increments are observed across all age groups, indicating that participants' ability to use the rules of the paradigm to their strategic advantage shows continued development. Strategic rule use is scored out of 18 points; mean scores and standard deviations for each age group are: 6-years (m=10.50, SD=4.00), 8-years (m=12.74, SD=3.42), 10-years (m=14.19, SD=3.58), 12-years (m=14.63, SD=2.38), 14-years (m=15.30, SD=1.78) and adults (m=16.42, SD=1.30). A Kruskal-Wallis test confirmed that the age groups score significantly differently from one another on this measure, $\chi^2 (5) = 70.81$; $p < .001$. Group differences investigated using Mann Whitney
U tests indicate a pattern of significant developmental differences in strategic rule use between 6 and 8-year olds and all other groups, with 10, 12 and 14-year olds scoring significantly differently from adults on this measure. Although not all group differences reach significance, the pattern of developmental differences in strategic rule use illustrated in Figure 10.5(b) demonstrates increments between all age groups. This developmental trajectory closely resembles that of the composite multitask performance score. The strategic rule use score contributes the greatest proportion of points to the composite multitask performance score (18 of 20), explaining this resemblance.

Whilst performing the multitask, it is possible to make performance errors (i.e. placing a blue item where a yellow item should be). The pattern of results in Figure 10.5(c) illustrates that very few participants made placement errors: only seven 6-year olds (17.5%), four 8-year olds (7.84%), two 10-year olds (6.45%), one 12-year old (5.26%), no 14-year olds (0.00%) and two adults (4.02%). A Kruskal-Wallis test confirmed that the age groups do not differ significantly from one another in their error making behaviour: $\chi^2 (5) = 8.24$, NS. Overall, the Mann Whitney U tests detailed in Table 10.8 support this lack of significant group differences, although a few group differences were observed. Significantly more 6-year olds committed errors than 14-year olds or adults, as did 12-year olds compared to adults.

**Rule breaking** represents the number of participants in each group who break the 'one-by-one' rule and the frequency with which they did so. Rather more participants broke rules than made performance errors: thirteen 6-year olds (32.50%), sixteen 8-year-olds (31.37%), eleven 10-year-olds (35.48%), two 12-year olds (10.52%), three 14-year olds (15.00%) and thirteen adults (26.53%). The pattern of z scores plotted in Figure 10.5(d) suggests a slight improvement in avoiding rule breaking behaviour between the three younger age groups compared to the three older age groups. However, the same number of 6-year olds and adults broke the rules and the age groups do not differ significantly from one another on this measure: Kruskal-Wallis test, $\chi^2 (5) = 6.16$, NS. Mann Whitney U tests in Table 10.8 confirm that none of the groups were significantly different to one another in terms of the number of participants who broke the ‘one-by-one’ rule. In addition to measuring the number of participants who broke the rules, we also measured the frequency of their rule breaks. Was it that adults broke the rules seldom, but younger children broke them more frequently? The frequency of rule breaks across age groups is illustrated in Figure 10.6. Although there is greater variation in the
frequency with which 6, 8 and 10-year olds broke the rules, no significant group differences emerge: Kruskal-Wallis test, $\chi^2 (5) = 6.84$, NS. Mann Whitney U tests in Table 10.8 indicate that the groups did not differ from one another in the frequency with which they broke the rules.

*Figure 10-6: Frequency of rule breaks*

In sum, different developmental trajectories have been identified for the various scores contributing to the multitask performance variable. An overall picture emerges of greater variation in the performance scores of younger children compared to older children and adults. Task switching shows a sharp developmental increase between 6 to 10 years, a plateau from 10 to 14 years and a further improvement between adolescence and adulthood. In contrast, strategic rule use demonstrates a more gradual, stable developmental course. There is some indication that rule breaking is more variable in children under 10 years of age; however no significant group differences were observed. No developmental trajectory is apparent for the number of errors made by participants in different age groups during multitasking; the overall incidence of errors was very low. The data support the conclusion that strategic rule use and flexibility in switching show the most developmental changes, and are thus the major determinants of successful multitask performance.
10.3  Consider the cognitive processes underlying multitasking

Multitasking requires the individual to perform multiple interleaved tasks within a limited amount of time. The time allowed is insufficient to finish all tasks, and the interleaving means that participants must move fluently between tasks to achieve successful performance. The time constraints and interleaving of tasks closely resembles the way in which we juggle multiple tasks in everyday life. The Battersea Multitask Paradigm was designed to incorporate these core aspects of multitasking. Following Burgess et al., (2000) we administered the Battersea via an invariant sequence of administration, described in Chapter 4. This sequence of administration generates six key variables, and the relationships between these variables can be used to investigate the cognitive processes underlying multitasking.

Burgess and colleagues (2000) used Structural Equation Modelling (SEM) to investigate the cognitive processes underlying multitasking. They found that a 3-factor model fitted their data best, and hypothesised that three cognitive systems support multitasking: a retrospective memory system, a planning system and a prospective memory/intention system. Their model is depicted in Figure 10.7.

Figure 10.7: Burgess et al., (2000) Structural Equation Model of Multitasking

Chi-square = 2.9, df = 5, p-value = 0.72; root mean square error of approximation (RMSEA) = 0.0, (0.09% CI for RMSEA = 0.00-0.094)

Ellipses show the theoretical cognitive systems supporting multitasking, boxes show which multitask variable contributes to each construct.

In order to perform structural equation modelling, it is necessary to have more than one measurement indicator contributing to each factor (in this instance to each underlying cognitive construct). It is ideal to have three independent but related measurement indicators contributing to each factor (Hoyle, 1995; Murayama, 1998). In addition, a minimum group size of 60 is recommended in order to have sufficient statistical power (Schumacker & Lomax, 1996). In their (2000) paper, Burgess and colleagues had two groups of participants (each N = 60), both of which were combined into the same analysis (N = 120) as they did not show any differences during separate group SEM analysis. As can be seen from the model, only one indicator contributed to the planning construct, and a statistical manipulation was performed to control this (the error variance for the indicator 'plan' was set to zero, see Burgess et al., 2000, page 856, for further detail).

In the present study, we do not feel we have sufficiently large group sizes to merit performing SEM. The purpose of conducting this modelling would be to evaluate how the pattern of relationships between multitask variables differs (or remains consistent) across different age cohorts. Given the data presented in the previous section, showing differential developmental trajectories for the key multitask variables, we cannot justify grouping age cohorts together for the purpose of SEM. Unfortunately, our groups are therefore too small to perform an initial SEM analysis to evaluate whether different age cohorts could validly be grouped together (as Burgess et al., 2000, did with patients and controls).

Instead, we shall investigate the relationship between multitask variables by correlating them with one another. The correlation matrices for the whole sample and for each age group are detailed in Tables 10.10 to 10.16, and discussed below. The correlation matrix of Burgess et al., (2000) is shown in Table 10.9 to illustrate the relationships they found between the same six key variables, generated by performance on their multitask paradigm, the Greenwich Task. The data in Table 10.9 support the 3-factor model in which three cognitive systems underlie multitasking. Two variables (performance indicators) contribute to retrospective memory (learn and remember), which correlate most highly with one another, and less strongly with all the other variables. Planning (plan) does correlate with plan following (follow), but all in all it stands alone as a relatively independent cognitive construct. Plan following, multitask performance (score) and recount all correlate highly and significantly with one another, supporting their combined contribution to the third cognitive construct, the prospective/
intention factor. These are the key relationships between variables that support the 3-factor model. In the correlation matrices that follow they are shaded in grey.

Table 10-9: Burgess et al., (2000) Correlation Matrix of Key Multitask Variables (N = 120)

<table>
<thead>
<tr>
<th></th>
<th>Learn</th>
<th>Plan</th>
<th>Follow</th>
<th>Score</th>
<th>Recount</th>
</tr>
</thead>
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<td>Plan</td>
<td>.01</td>
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<tr>
<td>Follow</td>
<td>.18</td>
<td>.37***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score</td>
<td>.38***</td>
<td>.11</td>
<td>.38***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recount</td>
<td>.38***</td>
<td>.15</td>
<td>.28</td>
<td>.46***</td>
<td></td>
</tr>
<tr>
<td>Remember</td>
<td>.51***</td>
<td>.25**</td>
<td>.20</td>
<td>.29**</td>
<td>.44***</td>
</tr>
</tbody>
</table>

*** Correlation significant at the 0.001 level, ** Correlation significant at the 0.01 level (2-tailed)

Table 10.10 details the partial correlation matrix for our whole sample tested with the Battersea Multitask Paradigm with age in months partialled out (alpha is set at .01 as there are 15 comparisons in each table). Overall, the pattern of relationships in our data set resembles that of Burgess et al., (2000).

Table 10-10: Age Partial Correlation Matrix of Key Multitask Variables – All Groups (N = 210)

<table>
<thead>
<tr>
<th></th>
<th>Learn</th>
<th>Plan</th>
<th>Follow</th>
<th>Perform</th>
<th>Recount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
<td>.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follow</td>
<td>.05</td>
<td>.87***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform</td>
<td>.17**</td>
<td>.32***</td>
<td>.57***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recount</td>
<td>.16</td>
<td>.21**</td>
<td>.45***</td>
<td>.62***</td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td>.56***</td>
<td>.12</td>
<td>.15</td>
<td>.25***</td>
<td>.22**</td>
</tr>
</tbody>
</table>

*** Pearson Correlation significant at the 0.001 level, ** 0.01 level (2-tailed)

Learning and remembering the rules are closely related with one another, and less strongly related to other variables, supporting the presence of an independent retrospective memory system. Follow, perform and recount correlate highly with one another, supporting their involvement in a prospective memory system. In our data set the three prospective memory variables also correlate with the planning variable in a pattern similar pattern to that observed by Burgess et al., (2000). Support for an independent planning system is less clear. It is interesting to note that Burgess et al., (2000) report that their data also fitted a 2-factor model, where retrospective memory remains an independent
cognitive system, but planning is included in the prospective/intention factor alongside follow, score and recount. Data from our whole sample could fit either the 3-factor or the 2-factor model. What does the pattern of relationships look like when the age cohorts are analysed separately?

**Table 10-11: Correlation Matrix of Key Multitask Variables – 6 Years (N = 40)**

<table>
<thead>
<tr>
<th></th>
<th>Learn</th>
<th>Plan</th>
<th>Follow</th>
<th>Perform</th>
<th>Recount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
<td>.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follow</td>
<td>.02</td>
<td>.77***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform</td>
<td>.35</td>
<td>-.03</td>
<td>.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recount</td>
<td>.09</td>
<td>.05</td>
<td>.46**</td>
<td>.72***</td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td>.52***</td>
<td>.18</td>
<td>.17</td>
<td>.29</td>
<td>.13</td>
</tr>
</tbody>
</table>

*** Correlation significant at the 0.001 level, ** Correlation significant at the 0.01 level (2-tailed)

**Table 10-12: Correlation Matrix of Key Multitask Variables – 8 Years (N = 51)**

<table>
<thead>
<tr>
<th></th>
<th>Learn</th>
<th>Plan</th>
<th>Follow</th>
<th>Perform</th>
<th>Recount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
<td>.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follow</td>
<td>.07</td>
<td>.89***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform</td>
<td>.05</td>
<td>.29</td>
<td>.55***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recount</td>
<td>.07</td>
<td>.26</td>
<td>.46***</td>
<td>.64***</td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td>.61***</td>
<td>.23</td>
<td>.34</td>
<td>.34</td>
<td>.32</td>
</tr>
</tbody>
</table>

*** Correlation significant at the 0.001 level, ** Correlation significant at the 0.01 level (2-tailed)

**Table 10-13: Correlation Matrix of Key Multitask Variables – 10 Years (N = 31)**

<table>
<thead>
<tr>
<th></th>
<th>Learn</th>
<th>Plan</th>
<th>Follow</th>
<th>Perform</th>
<th>Recount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
<td>.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follow</td>
<td>.06</td>
<td>.93***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform</td>
<td>.01</td>
<td>.71***</td>
<td>.77***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recount</td>
<td>.12</td>
<td>.31</td>
<td>.46**</td>
<td>.55***</td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td>.46**</td>
<td>-.26</td>
<td>-.14</td>
<td>.11</td>
<td>.02</td>
</tr>
</tbody>
</table>

*** Correlation significant at the 0.001 level, ** Correlation significant at the 0.01 level (2-tailed)
Chapter 10: Developmental trajectories in multitasking

Table 10-14: Correlation Matrix of Key Multitask Variables – 12 Years (N = 19)

<table>
<thead>
<tr>
<th></th>
<th>Learn</th>
<th>Plan</th>
<th>Follow</th>
<th>Perform</th>
<th>Recount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
<td>- .13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follow</td>
<td>- .47</td>
<td>.59**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform</td>
<td>- .35</td>
<td>.01</td>
<td>.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recount</td>
<td></td>
<td></td>
<td></td>
<td>- .05</td>
<td>-</td>
</tr>
<tr>
<td>Memory</td>
<td>.58**</td>
<td>.30</td>
<td>.01</td>
<td>- .05</td>
<td>-</td>
</tr>
</tbody>
</table>

*** Correlation significant at the 0.001 level, ** Correlation significant at the 0.01 level (2-tailed)
- Correlation cannot be computed because the variable is constant

Table 10-15: Correlation Matrix of Key Multitask Variables – 14 Years (N = 20)

<table>
<thead>
<tr>
<th></th>
<th>Learn</th>
<th>Plan</th>
<th>Follow</th>
<th>Perform</th>
<th>Recount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
<td>.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follow</td>
<td>- .24</td>
<td>.89***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform</td>
<td>.01</td>
<td>.25</td>
<td>.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recount</td>
<td>.38</td>
<td>.26</td>
<td>.29</td>
<td>- .12</td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td>.25</td>
<td>.08</td>
<td>- .04</td>
<td>- .17</td>
<td>.21</td>
</tr>
</tbody>
</table>

*** Correlation significant at the 0.001 level, ** Correlation significant at the 0.01 level (2-tailed)

Table 10-16: Correlation Matrix of Key Multitask Variables – Adults (N = 49)

<table>
<thead>
<tr>
<th></th>
<th>Learn</th>
<th>Plan</th>
<th>Follow</th>
<th>Perform</th>
<th>Recount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
<td>- .04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follow</td>
<td>- .06</td>
<td>.95***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform</td>
<td>.07</td>
<td>.51***</td>
<td>.57***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recount</td>
<td>.11</td>
<td>- .08</td>
<td>-.11</td>
<td>-.18</td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td>.68***</td>
<td>- .06</td>
<td>-.14</td>
<td>.01</td>
<td>.07</td>
</tr>
</tbody>
</table>

*** Correlation significant at the 0.001 level, ** Correlation significant at the 0.01 level (2-tailed)

Examination of the correlation matrices in Tables 10.11 to 10.13 reveals a fairly similar pattern of results for the youngest three age groups in the study (6, 8 and 10-years of age). Results support a close relationship between rule learning and rule memory, and their relative independence from all the other multitask variables. The three variables contributing to Burgess’ prospective memory factor also
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correlate highly with one another in the 6, 8 and 10-year old groups. In addition, planning correlates highly with plan following in all three groups, and with performance in the 10-year old group.

The correlation matrices of the 12 and 14-year old and adult groups (Tables 10.14 to 10.16) tell a slightly different story. In Table 10.14, the 12-year olds data support the relationship between the variables contributing to retrospective memory, as does the adult data set in Table 10.16. In contrast the 14-year olds are the only group in the sample to fail to show a relationship between rule learning and rule memory (Table 10.15). The 14-year olds in this study have lower mean IQ's than other participants, although these IQ differences do not reach significance. It is difficult to see how this might relate to the low correspondence between retrospective memory scores, given that the 14-year olds learn and remember the rules of the paradigm as well as other groups in the sample. Their rule learning scores range from 8-10 points with a mean of 9.15 (SD=0.48) and their rule memory scores range from 9-10 points with a mean of 9.30 (SD=0.47). Examination of the distribution of scores in a scatterplot (not shown here) suggests that within this narrow range the low correlation is caused by a mismatch of scores. For example, a child who scores 9 points on rule learning scores 10 points on rule memory and vice versa. In any case, the 14-year olds learn and retain rule based information to a high standard.

A strong relationship between planning and plan following is found in all three of these older age groups. This pattern mirrors that of the younger three participant groups, indicating a close relationship between planning and plan following across the entire sample. This fits the data discussed in the previous section, where planning and plan following follow similar developmental trajectories. Planning also correlates with performance in the adult group, but otherwise does not correlate with any other variables.

The pattern of correlation between plan follow, perform and recount is less clear in the 12, 14-year old and adult groups. This can be partly explained by the recount variable, upon which the majority of these older participants score close to ceiling. In fact, all 12-year olds scored maximum points on this measure, and as a result the correlation between recount and other variables could not be computed (see Table 10.14). In the 14-year old and adult groups, no significant relationship between recount and
any other variables is identified. Only in the adult group does performance correlate with plan following, as it did in the younger three age groups.

In sum, the patterns of correlation in all groups, except the 14-year olds, support the independence of rule learning and memory from the other multitask variables. This pattern corresponds to Burgess et al.'s (2000) retrospective memory construct. However, the pattern of relationships between the remaining multitask variables is different between the younger three age groups and the older three age groups. In the younger groups the pattern highlights relationships between plan, plan follow, perform and recount variables, supporting either a 3-factor or 2-factor model. In the older three age groups the pattern of relationships between variables is more difficult to determine, this being probably due to ceiling effects on the recount variable.

In the Figures below, we plot mean z scores based upon the 3-factor and 2-factor models proposed by Burgess et al., (2000). The retrospective memory factor is excluded from these graphs, as we did not set out to trace a developmental trajectory for retrospective memory, and scores in all groups were close to ceiling. Figure 10.8 illustrates the developmental trajectories of scores relating to Burgess' 3-factor model. The z score for the planning variable is plotted alongside a combined mean z score for plan follow, perform and recount, representing Burgess' prospective memory/intention factor.

*Figure 10-8: Three Factor Model of the Cognitive Processes Underlying Multitasking*
The results in Figure 10.8 demonstrate that planning and prospective memory follow a slightly different developmental trajectory from one another. Planning is equivalent between 6 and 8-year olds, and reaches ceiling by age 12-years. In contrast, prospective memory adopts a more stable pattern of incremental change across all age groups, although this change is much less pronounced between 12 and 14-year old participants (which could be due to sampling issues discussed previously).

Figure 10.9 illustrates the developmental trajectory of scores relating to Burgess' 2-factor model. In this model a combined mean z score for plan, plan follow, perform and recount is plotted, representing a prospective memory/ intention factor in a 2-factor model. The combined prospective memory factor in Figure 10.9 follows a steep developmental trajectory from 6 to 12-years of age, plateaus from 12 to 14-years, and shows a further increment between 14-years and adulthood.

Figure 10-9: Two Factor Model of the Cognitive Processes Underlying Multitasking

In sum, the combined prospective memory/ intention scores in both theoretical models show a pattern of significant development across childhood and into young adulthood. Both models indicate a developmental plateau between 12 and 14-years of age. However, this could represent a sampling issue rather than a developmental change. Recall that the 14-year old sample is not comparable to the other samples in this study in terms of IQ. Therefore, whilst this plateau will be considered further in the discussion, it will be interpreted with caution pending further work.
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10.4 Discussion

In this chapter we have drawn together a sample of participants ranging from 6 to 38-years who have all performed the same multitask paradigm. We found that multitasking improves across development; the developmental trajectory for multitask performance shows a pattern of performance increments between all the age groups studied. As a methodology, multitasking has a high ecological validity; it taps into the cognitive abilities necessary for the prospective organisation of multiple actions in our everyday lives (Alderman et al., 2003; Burgess et al., 1998; Wilson et al., 1998). As such, our results provide evidence to support the observation that as children mature they become increasingly able to ‘think ahead’ and to independently organise multiple day-to-day activities. Researchers have made significant progress in identifying the cognitive processes that support the prospective organisation of action in adulthood. Three underlying cognitive processes have been identified: retrospective memory, prospective memory and planning. We investigated whether the same cognitive processes support multitasking in childhood. Following Burgess and colleagues (2000), we administered our multitask paradigm via an invariant behavioural sequence which generates six key variables. Age-related performance on these key variables and the relationships between them inform our view of the cognitive processes supporting multitasking across development.

Retrospective memory has been identified as one of three cognitive processes supporting the organisation of future action. This is because in order to implement an intended action, the individual must have a memory of what the intended act is (Einstein & McDaniel, 1990; McDaniel & Einstein, 1992). Prospective memory makes it possible to remember that one has to do something; retrospective memory reminds one about the content of what that something is. In the multitask paradigm two variables measure retrospective memory: rule learning and rule memory. The aim of this study was not to assess the contribution of retrospective memory to multitasking, nor to trace the developmental trajectory of retrospective memory across childhood. Instead, we designed the study to keep retrospective memory scores both high and consistent across all age groups. This manipulation was necessary precisely because of retrospective memory developments in childhood (Schneider, 2002). In order to assess the development of multitasking fairly, we first had to ensure that participants of all ages had an equivalent knowledge of the rules of the paradigm. For the most part we achieved
this goal. Participants were required to pass a meaningful threshold to be included in the sample. The results indicate that even after this threshold was applied, the youngest children in the sample (6-years old) learned and remembered less information about the rules than all other participants. This difference could potentially influence the 6-year old participants’ scores on other aspects of multitasking. In fact, we investigated the influence of group differences in rule learning on multitask variables in the rule training study reported in Chapter 6. We found that group differences in rule learning did not have an impact on the majority of multitask variables, with the exception of the plan variable, scores on which improved when 6 and 8-year old children were trained to learn the rules to a high standard. Importantly, group differences in rule learning had no impact upon children's multitask performance scores. In sum, all participants included in the present analyses met rule learning criteria, and the fact that 6-year olds scored less well than other groups is not likely to influence their scores on the majority of multitask variables.

Planning is the second cognitive process supporting multitasking. The developmental trajectory of the planning variable suggests that 6 and 8-year old children plan at an equivalent, though very basic, level and that thereafter planning scores show a steep increase between 8-12 years of age at which point they reach ceiling. The lack of significant differences between 6 and 8-year olds planning scores is contrary to the results of other investigations into the development of planning skills (e.g., Levin et al., 1991; Welsh et al., 1991). It is possible that planning to perform multiple interleaved tasks is more complex and high-level than planning to perform tasks with a single, clearly defined goal. Therefore, planning to perform multiple tasks may not change much between 6 and 8-years of age. We did observe an increase in planning skills in children aged between 8 and 12-years of age, this finding is concordant with other studies investigating the normative development of planning (Levin et al., 1991; Welsh et al., 1991). By the age of 12 years the children in our study plan at an equivalent level to adults, however, this result does not represent the true developmental trajectory of planning skills. A number of studies evidence the continued development of planning through adolescence into young adulthood (Anderson et al., 1995, 2001; Levin et al., 1991). The most likely explanation for the trajectory identified in the present study is that our planning measure is not sophisticated enough to capture subtle differences in planning amongst older participants. Qualitatively, we found that adults did not give much detail in their initial plans, but when recounting their actions post-performance, their
statements revealed that they had had more sophisticated intentions in advance of performing the task. Burgess (personal communication) agrees that when planning is assessed verbally, adults often fail to explicate all the elements of their plan. A second explanation for our result lies in the way we have separated planning from performance. In the studies reported above, planning is typically not measured independently of performance (Levin et al., 1991; Welsh et al., 1991). For example, in tower tasks such as the Tower of Hanoi (used by Levin et al., 1991), planning is measured in terms of the number of moves a participant requires to complete the problem. If we were to score planning on the basis of performance, we might measure how many times a participant selects a yellow item first on each subtask, or how many times they fill a small cluster first etc. In other words, planning ahead would be measured using the same scores that we use to measure performance. If this were the case, the developmental trajectory of a ‘performance-based-planning’ measure would obviously fit the trajectories described in the literature, with development continuing beyond 12 years into young adulthood. We discuss the relationship between planning and plan following further below.

Prospective memory is the third cognitive process supporting multitasking and the organisation of future action. Three variables contribute to the prospective memory factor: plan follow, multitask performance and recount. Individually these variables exhibit quite different developmental trajectories; their combined trajectory is plotted in Figure 10.8 and supports the ongoing development of prospective memory through childhood and adolescence into young adulthood.

Plan following shows developmental differences across all age groups and has a similar developmental trajectory to planning. This similarity is mostly explained by the fact that the plan following score is based upon the planning score, as it represents the planning score minus any deviations from that plan. When planning and plan following scores deviate from one another, this indicates that the original plan has been poorly implemented. Only 6-year old children were unable to implement the plans they had made, all other participant groups being able to execute their plans effectively. Planning and plan following are not typically separated in studies investigating the development of planning skills in children. However, some studies do separate the plan from the implementation of the plan. For example, Klahr and colleagues (1993) observed that when young children perform tower tasks they can rush ahead and waste moves, potentially due to poor inhibitory control. To reduce
inhibitory demands these researchers introduced a puppet to their paradigm. Children were asked to
tell the puppet where to move, rather than make the moves themselves. This manipulation led to more
efficient planning of moves, supporting the hypothesis that inhibitory control plays a role in the
successful implementation of a plan.

Increments in multitask performance scores are evident between all age groups in this study, indicating
a strong developmental trajectory for multitasking skills from early childhood to young adulthood. As
multitasking is reliant upon the cognitive skills involved in the organisation of future action, we interpret
our results as evidence that the ability to organise future behaviour develops from 6-years of age
through to young adulthood. The finding that multitask performance develops across childhood is
consistent with the results of two studies that have investigated multitasking in children aged 6 to 16-
years (Emslie et al., 2003; Martin & Kliegel, 2003). Furthermore, our study extends the trajectory to a
young adult population and enables investigation of the processes underlying multitasking. Multitask
performance can be broken down into task switching, error making and rule breaking, and strategic rule
use.

Successful task switching requires inhibitory control and cognitive flexibility. Attention to the current
task must be inhibited in order to switch successfully to the next task (Kliegel et al., 2002; Martin et al.,
2003). Task switching in multitasking follows a unique developmental trajectory, developing rapidly
between 6 and 10 years of age, reaching a plateau between 10 and 14 years and peaking again
between adolescence and adulthood where it reaches ceiling. Cognitive flexibility and switching have
been investigated in a number of studies of normative development (Anderson, 1998; Chelune & Baer,
1986; Levin et al., 1991; Welsh et al., 1991). Cognitive flexibility is typically measured using card-
sorting tasks, which involve sorting cards and switching along a number of different dimensions (e.g.,
shape, colour, number). Research indicates that cognitive flexibility measured on two dimensional card
sort tests reaches adult levels of performance by 12-years of age (e.g., Levin et al., 1991; Welsh et al.,
1991). Our results fit this pattern in that we find significant development of cognitive flexibility in
children aged 6 to 10-years of age. Why did children in our study not reach adult levels of switching
performance by age 12-years? First, in the card-sorting studies discussed above children alternated
sorting between only two dimensions. The switch demands of the multitask paradigm are greater;
there are three subtasks to switch between, and switching is reliant on self-initiated strategic thinking rather than instructions from the experimenter. Second, and related to this first point, the multiple demands made by multitasking operate within a limited capacity system in which processing space is confined by the limitations of working memory (Kliegel et al., 2002; Shallice & Burgess, 1996). It is possible that there is a trade off between switching and the complex demands of strategic rule use in the 10 to 14-year old participants, and that only the adults can free up the resources necessary to achieve optimal performance. In line with this interpretation, switching on more complex tasks such as the ID-ED (intra-dimensional/ extra-dimensional) shift task shows a more protracted developmental trajectory (De Luca et al., 2003). The developmental trajectory of inhibitory control follows a very similar pattern of strong gains up to 12-years of age at which point performance nears adult levels (Anderson, 2002; Levin et al., 1991). In addition to task switching two other aspects of multitask relate to inhibitory control: error making and rule breaking. Very few participants made performance errors and no significant age group differences were observed for this measure. Likewise, whilst rule breaking behaviour was more variable in children up to age 10-years of age, no group differences were found in the number of participants breaking the rules or the frequency of their rule breaks. These results are not in line with the developmental trajectory of inhibitory control. It is possible that rule breaking in the multitask paradigm does not place significant demands on inhibition functions. The relationship between inhibition and multitasking in childhood is worthy of further investigation.

Strategic rule use is an important aspect of multitask performance. The developmental trajectory of scores on this measure follows a pattern of incremental improvements across all age groups. This finding fits the trajectories identified in normative developmental studies of problem solving and strategy use, in which these cognitive skills continue to show functional gains into adolescence (Anderson, 1998; Anderson et al., 1995, 2001; Levin et al., 1991).

Finally, although the recount variable was flawed in its design (too simple) with participants above 12-years of age scoring at ceiling, results from the younger three age groups indicate that children's ability to recount what they have achieved during multitask performance develops between 6 and 12-years of age. This possibly reflects developments in the Supervisory Attention System and the ability to monitor
the success of one's own performance. Ceiling scores in older participant groups prevent us from drawing further conclusions about the development of this cognitive skill.

So far this discussion has focused on the existence of three cognitive processes supporting multitasking: retrospective memory, planning and prospective memory. In their original paper Burgess and colleagues (2000) report that a 2-factor model also fitted their data well. In this model retrospective memory and prospective memory are the two cognitive processes underlying multitasking with planning becoming a score contributing to prospective memory.

Unfortunately, due to the lack of an adequate sample size and of sufficient numbers of indicator scores, we are unable to perform structural equation modelling on our data set. As such, we are unable to formulate a developmental model of the processes supporting multitasking in children and are limited to extrapolating from an adult model. Having said this, our data support the adult 3-factor model rather well. The patterns of correlation indicate that the two retrospective memory variables (rule learn and rule memory) are closely related to one another and relatively independent of all other variables, supporting the involvement of an independent retrospective memory system. The three prospective memory variables (plan follow, performance and recount) are also closely related to one another, at least in the three youngest participant groups.

The key difference between the 3-factor and 2-factor models is that in the 2-factor model planning should be included within the prospective memory factor. We can assess how well our data fit either model by looking at how well planning correlates with the three prospective memory variables. Although the correlation between plan and plan follow is consistently high across almost all age groups, this high correlation is expected because the plan following score is based upon the planning score. The real test of whether planning is independent of prospective memory comes by looking at the correlation of planning with performance and recount. In the majority of groups the correlation between planning and performance is very low, although in the 10-year old and adult groups this relationship is stronger. The correlation between planning and recount is consistently low across all age groups. Therefore, the pattern of relationships between variables does seem to support the 3-factor model. One further piece of evidence supports the independence of planning from prospective memory. In the
training study reported in Chapter 4, training participants to enhance their retrospective memory scores impacted upon planning but had no effect on performance. This supports the existence of independent connections between retrospective memory and planning, and retrospective memory and performance. To end on a note of caution, this discussion is, of course, speculative pending modelling. At present what can be said is that both planning and prospective memory appear to play an important role in the organisation of future action in children as well as in adults.

Two further patterns emerge from the data set that are worthy of mention. Firstly, on the four key variables that show developmental differences (plan, plan follow, performance and recount), the variation in scores reduces substantially as participants become older. This pattern of lower standard deviations with increasing age is the opposite of the pattern observed at the other end of the life-span with older adults (Martin & Schumann Hengsteler, 1996). Performance on tests of prospective memory and executive functions in older adults becomes less stable over time (West, Murphy, Armilo, et al., 2002). In studies of cognitive functions in ageing, the level of variation in performance increases proportionally to increasing age (Salthouse 2001, 2003).

The second pattern to emerge concerns the prospective memory factor in both the 3-factor and 2-factor models, plotted in Figures 10.8 and 10.9. In both models there is no difference between the prospective memory scores of 12 and 14-year old children in the sample. The issue is whether this result represents a genuine plateau in the development of prospective memory, or whether it is an artefact of our data set. There is evidence to support both sides of the argument. Cognitive functioning may reach a stable period around the onset of puberty when development temporarily plateaus, before further cognitive development occurs later in adolescence and into adulthood (McGivern, Anderson, Byrd et al., 2002). Adolescence is a particularly important time for the development of the prefrontal cortex and the cognitive functions it supports, which has been implicated in the organisation of future action (e.g., Burgess et al., 2000). Changes in both the structure and function of the brain during adolescence impact upon performance on tests of executive function (e.g., Giedd et al., 1996, 1999; Sowell et al., 2001), as do the hormonal changes associated with puberty (Davies & Rose, 1999). Two studies suggest that in late childhood and early adolescence (the 12 to 14-year age range), performance on executive function tasks is mediated by prototype brain systems that are posterior to
Chapter 10: Developmental trajectories in multitasking

the regions of the brain that mediate performance on the same tasks in late adolescence and young adulthood (Bunge et al., 2002; Rubia et al., 2000). Normative studies of the development of executive functions also support a significant period of development in late adolescence and again in young adulthood (De Luca et al., 2003). Together, these studies indicate that the cognitive skills mediated by the prefrontal cortex do not undergo any substantial changes in early adolescence. However, it is equally possible that the plateau observed in our data set is an artefact resulting from our sample. Our 14-year old group is qualitatively different from the other groups of children included in the study. They were recruited from a different geographical region and, as a group, have a low average IQ. This makes it difficult to draw conclusions about developmental differences in prospective memory involving this group. In the future it would be very interesting to conduct a study assessing the trajectory of prospective memory development across adolescence, focusing on adolescents at different stages of puberty.

10.5 Summary of limitations and recommendations for future studies

We have highlighted a number of limitations in the data included in this chapter. First, we included data from multitask studies which used two alternate administration procedures. Some participants were trained to learn the rules of the multitask paradigm, whilst others were not. To counter this training difference, we set inclusion criteria for this chapter using the 'untrained' part of the rule learning score: participants' answers to cued questions about the rules. All participants in the analyses reported here met these inclusion criteria. Second, the sample is not balanced for IQ. We measured IQ by assessing performance on two sub-tests of the Weschler intelligence scales. Whilst this method only provides an estimate of IQ, our groups do not score at an equivalent level. The 6 to 12-year old groups are of average intelligence, the 14-year old group is of low average intelligence and the adult group is of high average intelligence. Although there is no evidence to support a link between multitasking and intellectual ability, there is evidence to support a relationship between frontally mediated cognitive abilities and IQ (Duncan, Seitz, Kolodny et al., 2000). Therefore, this IQ difference has the potential to impact upon group differences in multitask performance. However, the majority of age groups did have equivalent scores on the IQ measures and we can be confident that age group differences observed across the 6 to 12-year old groups are not the result of group differences in IQ. Third, older
participants reached ceiling on some variables, for example planning and recounting. These ceiling effects mean that the developmental trajectories of these variables cannot be traced. Finally, we failed to measure multiple performance indicators for each of the cognitive processes hypothesised to support multitasking. In combination with our small sample size, this meant that we could not perform Structural Equation Modelling on our data set. Hence the developmental trajectories we have mapped are derived from an adult model rather than a developmental one.

It would be of value to conduct a study with a new sample of participants who have all been trained to learn the rules of the paradigm in the same way. Multiple indicators for each underlying cognitive process could be included; for example independent measures of prospective and retrospective memory and planning could be taken. The age cohorts could be more clearly defined and the sample could be extended to include older adults too.

In addition, it should be possible to track individual trajectories on key variables using the present data set. This would enable us to ask questions about intra-individual consistency between scores. If a person is a good planner, does this make him or her a good performer and a good recounter? This would be a particularly valuable analysis in the younger age groups of participants who do not score at ceiling on any of the key variables.

10.6 Chapter summary

In previous chapters we demonstrated developmental differences in multitasking in participants aged from 6-years to young adulthood. Having identified these developmental differences, we mapped the developmental trajectory of multitask performance across all these age groups. Our results support the development of the organisation of future behaviour from childhood into young adulthood. The second aim of this chapter was to map the developmental trajectories of the cognitive processes underlying the organisation of future behaviour. Results support different developmental trajectories for planning and prospective memory.
11

Conclusions and implications for future studies

11.1 Conclusions

The ability to organise behaviour lies at the very heart of competency in everyday life (Burgess, 2000). Our professional and personal lives are centred around future goals. Each day we plan and organise multiple activities, flexibly switching from one activity to another, adjusting and re-prioritising intentions in the face of unexpected events, successfully monitoring completion or deferment of these activities, and interleaving them to perform them in a strategic and time efficient way. Research with adults has advanced our understanding of the cognitive processes underlying the ability to organise future oriented behaviour, and multitasking has been developed as a methodology that taps into these underlying processes (Burgess, 2000; Shallice & Burgess, 1991). The central aim of this thesis was to investigate the development of the organisation of future behaviour in childhood. We outline five ways in which our work has addressed this aim.

[1] Creation of a ‘life span’ multitask paradigm

We have designed a multitask paradigm that can be used to test the organisation of future behaviour in participants from 6 years of age to adulthood. The Battersea Multitask Paradigm has all the requirements of a multitask situation: multiple interleaved tasks can only be performed one at a time, adequate performance is self determined and no immediate feedback is provided (Burgess, 2000). Performance is governed by time-based and rule-based constraints, and successful performance
Chapter 11: Conclusions and implications for future studies

requires the creation and execution of delayed intentions. This multitask paradigm enabled us to assess multitasking skills in children and adults, the youngest of whom was 5 years of age and the oldest of whom was 52 years of age. We anticipate that our multitask paradigm will prove useful in mapping the developmental trajectory of the organisation of future behaviour across the life span, extending the population assessed to include older adults. In addition, our paradigm extends existing research investigating multitasking in children, as its design and administration enables us to investigate distinct cognitive processes contributing to multitask performance.

[2] The ability to organise future behaviour develops through childhood into young adulthood
We have presented data that support developmental differences in multitasking across childhood and into young adulthood. Multitasking taps into the cognitive processes underlying the organisation of future behaviour and, as such, our data indicate that the ability to organise prospective/‘future-oriented’ actions develops between 6 years of age and young adulthood. As this ability is central to competency in everyday life and independent living, this pattern of development reflects the growth of independence from young childhood into young adulthood. During the pre-school years the precursors to the organisation of future behaviour are developed in the context of daily routines, which include anticipation, expectation, intention and basic planning skills (Benson, 1994; Haith et al., 1994; Hudson et al., 1995). It is when children begin school that they are first called upon to become more independent, engaging in future actions such as bringing home letters and completing homework assignments (Meacham & Colombo, 1980). The level of responsibility assumed by children continues to increase throughout the school years as they become increasingly able to co-ordinate both educational and social commitments. In adolescence, children take further steps towards independence as they attend to future employment or educational opportunities, and engage in social activities out with the sphere of parental control (Spear, 2000). By young adulthood the independent management of day-to-day life has emerged, reflecting the ability to co-ordinate and implement multiple goal-directed actions over the course of a day, a week or a year (Haith, 1994).

[3] Similar cognitive processes underlie multitasking in childhood and adulthood
Adult research has identified three cognitive processes involved in multitasking. These are retrospective memory, planning, and prospective memory, which is the key cognitive process
underlying the ability to create and execute delayed intentions (Burgess et al., 2000; Kliegel et al., 2002). In adults these three processes are distinct, although they are related to one another via their respective roles in the organisation of future action. Retrospective memory supports planning and prospective memory processes, which are in turn related to one another (Burgess et al., 2000). Our investigations indicate that similar cognitive processes underlie multitask performance in children, but the patterns of relationships between these processes may change with age. Specifically, in children aged 6-10 years, variables contributing to planning and prospective memory are highly correlated, indicating that the cognitive processes supporting multitasking in younger children may be quite interrelated. However, in older children and adults, the pattern of relationships between variables is different and they appear to be more independent of one another, perhaps reflecting the increasing functional specialisation of these cognitive processes with maturation (Bishop, 1997; Karmiloff-Smith, 1992, 1998). Research has shown that young children display greater levels of activation when performing tasks dependent on the prefrontal cortex (Casey et al., 2000), and that they recruit more and different brain regions from adults (Bunge et al., 2002), providing a biological basis for the pattern of relationships observed here. In our study retrospective memory variables were closely related to one another in participants of all ages, but not to variables contributing to planning or prospective memory processes, supporting the independence of retrospective memory from these other cognitive processes even in young children.

The cognitive processes underlying multitasking have different developmental trajectories

The design and administration of our multitask paradigm enabled us to investigate the development of some of the cognitive processes underlying the organisation of future behaviour (note that because we manipulated retrospective memory to be constant our research does not inform on the developmental trajectory of retrospective memory). These include planning and plan enactment, prospective memory, strategic rule use and performance monitoring. We found different developmental trajectories for these different aspects of multitask performance. This indicates that whilst all these processes are involved, their relative contribution to the organisation of future behaviour may vary across developmental time. Furthermore, these patterns of differential development are compatible with developmental trajectories of executive functions in childhood. This evidence supports models postulating the involvement of executive functions in the organisation of future behaviour (Kliegel et al., 2002).
Chapter 11: Conclusions and implications for future studies

The overall picture is that the co-ordination of multiple prospective actions may present particular difficulties for children under 10. When multiple task demands are removed, 6 and 8-year old children are able to formulate strategic plans and to use rules governing task performance to good effect. In fact, their strategic rule use under single task conditions is on a par with that of 10-year olds under multitask conditions, indicating that their greatest difficulty is in co-ordinating performance across multiple tasks and switching strategically between them. Whilst 6 and 8-year old children have significant difficulty switching between multiple tasks, 10-year old children are able to switch more efficiently between tasks, indicating that co-ordinating performance across multiple tasks is relatively mature by this age. Task switching requires the creation and execution of delayed intentions (intentions to switch to other tasks) and as such provides an index of prospective memory. A rapid development in task switching ability between 6 and 10-years of age has also been observed in a multitask study of children’s prospective memory (Martin & Kliegel, 2003). Task switching is also influenced by cognitive flexibility and inhibitory control, and both these executive skills develop rapidly between 6 and 12 years of age (Anderson, 2002; Levin et al., 1991; Welsh et al., 1991). It is likely that up until age 10 years, the ability to perform multiple future actions is strongly influenced by the development of prospective memory and executive skills such as cognitive flexibility and inhibitory control.

Developments in planning and performance monitoring skills may influence the organisation of future action up to age 12, a pattern of results that is concordant with the significant development of planning skills during the 6 to 12-year period (Anderson, 2002; Levin et al., 1991; Welsh et al., 1991). At age 12 performance monitoring reaches ceiling, which does not reflect an adult level due to the design of our performance monitoring measure. However, in children under 12 there is a pattern of significant development of this ability. Between 12 and 14 years of age the development of future oriented abilities appears to plateau, which may or may not reflect the cortical reorganisation that takes place around the onset of puberty (Lewis, 1997; Rubia et al., 2000). An alternative explanation is a sampling bias in our data set. Finally, a period of further developmental gains in planning, strategic rule use and task switching occurs between adolescence and young adulthood, possibly representing a final honing of the skills underlying the organisation of multiple future actions and the functional maturation of the prefrontal cortex.
High functioning children with autism spectrum disorder have multitasking deficits

The ability to organise complex future-oriented behaviour is not only vulnerable to impairment by traumatic brain injury; recent research has focused on impairments in this ability in children with developmental disorders. Multitasking deficits have been reported in children with pervasive developmental disorders (Emslie et al., 2003), but the nature of these deficits was not specified. Our study is the first empirical investigation of multitasking in autism spectrum disorder, and our multitask paradigm enabled us to investigate which aspects of multitasking present particular difficulties for high functioning children with autism spectrum disorders; hence which underlying cognitive abilities may be impaired. The children in our study produced less strategic plans and were impaired on various aspects of multitask performance compared to matched controls. Planning deficits in autism spectrum disorder are well documented (Geurts et al., 2004; Hughes et al., 1994; Ozonoff et al., 2004), and performance difficulties may be related to prospective memory deficits or deficits in the executive processes supporting the realisation of delayed intentions, such as cognitive flexibility (Bennetto et al., 1996; Ozonoff et al., 1991, 1994). Our results need to be replicated and further investigation of the cognitive processes underlying these multitasking deficits is required. Multitasking deficits have also been identified in children with ADHD (Clark et al., 2002; Kliegel & Kerber, in prep.; Siklos & Kerns, 2004). It will be interesting to explore whether the multitasking deficits in these developmental disorders are caused by different patterns of impairment of underlying cognitive processes.

11.2 Implications for future studies

Many questions and possibilities for future research arise from this study. We have identified developmental differences in multitask performance in participants across a wide range of ages. On the basis of these group differences we have suggested developmental trajectories for the cognitive processes underlying multitasking. These trajectories need to be explored in a longitudinal study to investigate whether the developmental differences observed truly represent developmental changes in children's ability to organise future behaviour. It would also be advantageous to measure multiple indicators of the cognitive processes hypothesised to underlie the organisation of future action, as this
would enable us to model the relationships between these underlying processes in the same children over time.

Our results raised an interesting question about whether the organisation of future behaviour reaches a developmental plateau during adolescence. Unfortunately we were limited by our sample of 14-year olds, whose low IQ's made it difficult to compare them to our other participants. It has been suggested that at the onset of adolescence, the development of other cognitive abilities subsumed by the prefrontal cortex 'level off,' as the prefrontal cortex undergoes substantial structural and functional reorganisation during this time (Giedd et al., 1999; McGivern et al., 2002.). Multitasking relies on frontal lobe functioning and it would be interesting to investigate whether adolescence represents a distinct developmental period in the organisation of future behaviour.

In adults the prefrontal cortex is activated during performance on prospective memory tests in functional imaging studies (e.g., Burgess et al., 2001, 2003; Yamadori et al., 1997), as well as studies of event related potentials (ERP's: Leynes et al., 2003; West et al., 2000). In future it would be interesting to investigate regions of activation in children performing prospective memory tasks to investigate whether children recruit similar or more distributed brain regions than adults.

We would also like to extend the use of our paradigm to older adults, as this would enable us to investigate the developmental trajectory of multitasking across the life span using the same paradigm for children and adults. Our multitask paradigm is challenging to both children and young adults, and we anticipate that it would also be suitable for use with older adults. This would compliment existing research, which has used multitask paradigms to investigate complex prospective memory in normal ageing and found performance decrements in older adults compared to younger adults (Kliegel, 2003a; Martin et al., 2003). Our paradigm enables us to explore which aspects of multitasking decline, and hence which underlying processes may be vulnerable in normal ageing.

In turn, theory derived from ageing research can also be relevant to research in child development. Prospective memory declines in normal ageing may be attributed to changes in frontal lobe functioning (West, 2000), or declines in speed of information processing (Salthouse, 2000, 2001). We have
reviewed literature supporting a close relationship between frontal lobe development and the development of future organisation skills (Andersen et al., 2000; Casey et al., 2000). Similarly, cognitive development in childhood is hypothesised to be driven by changes in information processing capacity (Case, 1995). The relationships between prospective memory, executive functions and the speed of information processing across development may prove a fruitful area for further research.

We wish to further investigate the ecological validity of our multitask paradigm. In adults multitask paradigms successfully discriminate patients with frontal lobe damage who have selective deficits in the ability to organise future behaviour in everyday life. As our multitask paradigm was designed to capture the less structured nature of multitasking in everyday life, we believe that these adult frontal lobe patients would also show performance decrements on our paradigm. We did find multitask deficits in children with autism spectrum disorder who were also reported to have difficulties organising activities in everyday life. However, the questionnaire we used to investigate these difficulties was designed to assess executive function difficulties in children. It would have been useful to use a complimentary prospective memory questionnaire or the children's DEX questionnaire, designed to specifically investigate dysexecutive problems in children (Emslie et al., 2003). In adults the 'intentionality' factor underlying the DEX questionnaire is specifically related to performance on multitask paradigms (Wilson et al., 1998). To date no studies have investigated the underlying factor structure of the children's DEX questionnaire. It would be interesting to see whether the underlying structure had the same or different factors as in adults, and whether performance on multitask tests related to any of these.

We would like to extend our research investigating multitasking deficits in children with other developmental disorders. We reported multitasking deficits in children with autism spectrum disorder and hypothesised that these might be attributable to prospective memory deficits and/ or impairments in the executive functions supporting multitasking such as planning and cognitive flexibility. In future studies we would take independent measures of executive functions and prospective memory, and see how these correlate with multitask performance. Multitasking deficits have also been reported in children with ADHD and it had been proposed that these may be attributable to high-level deficits in strategy application (Clark et al., 2002; Siklos & Kerns, 2004). In future it would be interesting to
investigate whether the underlying causes of multitasking impairments in children with autism spectrum disorder and children with ADHD are different, by comparing multitask performance within the same study. Within task manipulations varying the demands made upon inhibitory control (e.g., Kliegel, 2003b), strategy use and cognitive flexibility would also be informative.

The fact that the ability to organise future actions is vulnerable to impairment in childhood, as well as in adulthood, has implications for rehabilitation. Our multitask paradigm enables us to identify which aspects of multitasking present the greatest difficulty to children with acquired brain injuries or developmental disorders, which would be of use in targeting interventions. Adults with prospective memory deficits have been successfully taught to use pagers and diaries as memory aids (Evans, Emslie & Wilson, 1998; Manly, Hawkins, Evans et al., 2002). Children are able to make use of external cues to facilitate prospective memory (Beal, 1985; Kreutznner et al., 1975; Meacham & Colombo, 1980; Passolunghi et al., 1995), so it is possible that these strategies could be used to rehabilitate children too. A key difference is that adults with acquired brain injury of dementia have 'lost' their ability to organise future actions as part of their day-to-day lives. However, children may not develop this independence on the first place. Constructing appropriate interventions for children who have difficulties organising future behaviour represents a challenge for future research.

In conclusion, we believe that we have invented a new task - the Battersea Multitask Paradigm - with the unusual quality of being useable and challenging to 6 year olds as well as to adults and atypical populations, which can reveal the component parts of the cognitive processes underlying the organisation of future-oriented behaviour.
References


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Appendix 1

Battersea Multitask Paradigm

Administration Instructions

&

Score Sheet
Appendix 1: Battersea Multitask Paradigm Administration Instructions & Score Sheet

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School: __________________________________________
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Video Code: _______________________________________

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Age: ___________________________ Gender: ________________________
SPSS: __________________________

What colour is this?

Yellow –
Blue –

Handedness
Appendix 1: Battersea Multitask Paradigm Administration Instructions & Score Sheet

Introduction
- Here are three games
- In each game you can get points
- First I'm going to teach you how to play the games one at a time
- Then you are going to play them all at the same time

Counters
This game is called counters. Here are counters to sort out - you put them in these squares.
(Place two blue counters in the blue square, and two yellow counters in the yellow square, taking care to place counters one-by-one).

A blue counter goes on blue like this...

A yellow counter goes on yellow like this...

You can only pick them up one by one.

You try to fill up this square.

Watch to check that the child is placing the counters in the correct squares, and picking them up one-by-one. Once the child has filled both practice squares, say:

Remember I told you that you score points in these games? There are two good ways to score points:

The first is to fill up the squares. For each square you fill, you get lots of extra bonus points. It's good to fill squares. This square is all filled up (demonstrate), so you get lots of extra bonus points. This square is not filled up (demonstrate by removing a counter from a practice square), so you don't get extra bonus points for it.

The other good way to score points is to remember something special about the colour yellow. In this game, yellow things are worth more points than blue. It is a good idea to use a lot of yellow things when you play this game, because yellow things are worth more points than blue (demonstrate by holding yellow counter in the air higher than a blue counter).

Remember then, yellow things are worth more points than blue, and full squares, yellow or blue, score lots of extra bonus points.

Beads
This game is called beads. Here are beads to sort out - you put them in these pots. (Place some blue beads in the blue pot, and some yellow beads in the yellow pot, taking care to place them one-by-one).

Blue beads go into the blue pot like this...

Yellow beads go into the yellow pot like this...

Remember you can only pick them up one by one.

You try. Watch to check that the child is placing the beads in the correct coloured pots, and picking them up one-by-one. Once the child has tried a few of each, say:

Lets fill up the yellow pot so that you can see what a full pot looks like, I'll help you. (Fill up the yellow pot with the child...)
Good. Now, do you remember I told you the two good ways to score points in these games?

If the child remembers, affirm what he/she is saying. If the child looks blank, say the point scoring rules again. Either way, you say the rules to the child using the phrases below.

The first way to score lots of points is to fill things up. Just like you scored extra bonus points for filling up squares (gesture to counters game), in the beads game you score extra bonus points for filling up a whole pot. This pot is all filled up (demonstrate), so you get lots of extra bonus points. This pot is not filled up (demonstrate the blue pot which is not full), so you don't score extra bonus points for it.

You get extra bonus points for every pot you fill, yellow or blue, remember then, filling up pots is a good idea.

The other good way to score points is to remember something special about the colour yellow. In this game, yellow things are worth more points than blue. It is a good idea to use a lot of yellow things when you play, because yellow things are worth more points than blue (demonstrate by holding yellow bead in the air higher than a blue bead).

Remember then, yellow things are worth more points than blue, and full pots, yellow or blue, score lots of extra bonus points.

Caterpillars
This game is called caterpillars. Here are caterpillars to colour in. What colour should this caterpillar be? (Point to the blue caterpillar)

I'll colour this one in (demonstrate by colouring the blue caterpillar). Whilst colouring illustrate that the child should only colour circles one-by-one. Also illustrate that the circle should be mostly covered, and that messy colouring is OK. Use the following phrases:

You should only colour the circles in one-by-one, just like you picked up the beads and counters one-by-one.

I'm a bit of a messy person colouring in (go over the sides of the circle as you say this), so it's OK if you are too...

You should cover all of the circle (demonstrate by colouring half a circle), so this is not enough colouring – you should colour all of the circle (demonstrate).

What colour should this caterpillar be? You colour it in.
Watch to check that the child is colouring one circle at a time, and covering most of each circle.

Good. Now, can you tell me what you get if you fill a whole caterpillar up? (affirm the child's response if correct, if not repeat the rule, either way say the rule again using the following phrases)

Filling up a whole caterpillar gets you lots of extra bonus points. So this caterpillar is full, and this caterpillar is full, so you get lots of extra bonus points for each one.

And, do you remember what is special about yellow things in this game? (affirm the child's response if correct, if not repeat the rule, either way say the rule again)

Remember then, yellow things are worth more points than blue, and full things, yellow or blue, score lots of extra bonus points.

Once the practice session is finished remove practice materials from the table and place the 3 tasks of the Battersea Multitask Paradigm on the table in front of the child (arranged in the same order as the practice tasks)
‘The game’

Now you know how to play the 3 games. Here’s how we play all 3 games at the same time:

- Look at this timer
- This is how much time you have to try all 3 games
- It is not very long – only 3 minutes
- The game starts when I turn over the timer like this and the sand goes from the top to the bottom
- The game stops when all the sand has reached the bottom of the timer

- Before you play, you have to learn the rules.

Rules

There are 4 rules:

- Before the sand has gone from the top to the bottom, you must try all 3 games – some beads, some caterpillars and some counters. You can't miss out any of them. You have to try all 3.
- You won't be able to finish any of them, so don't try to. There are too many beads to sort out. There are too many caterpillars to colour in. There are too many counters to place. You just have to try all 3 games.
- You get more points for yellow than blue. Don't forget then, yellow gives you more points, you should do more yellow things.
- You get extra bonus points for every pot, caterpillar or square you fill up. You should fill up the things you do.
- Only one thing in your hand at a time. One bead, one crayon or one counter. So, only one in your hand, not two (demonstrate by holding more than one bead in your hand).

You must not break the rules.
Appendix 1: Battersea Multitask Paradigm Administration Instructions & Score Sheet

You need to remember these 4 rules because I am going to ask you what they are. Listen carefully and say them right after me (get participant to repeat each rule after you):

- Try all 3 games before the sand runs out.
- Yellow gets more points than blue.
- You get extra/bonus points for every thing you fill up.
- One thing in your hand at a time.

**Free Recall Rule Learning**

Now - can you tell me the 4 rules?

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**Cued Recall Rule Learning**

How many games are there? (3)

What is special about yellow things? (More points than blue)

How many of the games should you try? (All/3)

How long do you have to play the games? (3 mins./until the sand/time runs out)

Do you think you could finish all of the games before the sand runs out? (No)

When does the game stop? (After 3 mins./when the sand/time runs out)

Can you have more than one thing in your hand? (No)

Why should you go as quickly as you can? (Get lots of points/before time runs out/fill things up)

Why should you try to fill up squares and caterpillars and pots? (To get extra/bonus points)
Planning

I want you to get as many points as you can. How will you play the game to get as many points as you can? (Record verbatim)

*Tell me as well as show me

*Note where a plan is prompted by putting a (P) next to the prompted comment.

Well done – now we’re ready to play. Remember to get as many points as you can:

- Try all 3 games before the sand runs out.
- Yellow gets more points than blue.
- You get extra/ bonus points for every thing you fill up.
- One thing in your hand at a time.
Appendix 1: Battersea Multitask Paradigm Administration Instructions & Score Sheet

Perform

Keep an eye on the timer – I don’t want it to stop before you have tried ALL 3 games.

Ready…steady…GO!

(Turn over timer and start stopwatch)

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<th>Task: Bd/Cat/Cn</th>
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<tr>
<td>Stop!</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Recount & Rule Memory)
Appendix 1: Battersea Multitask Paradigm Administration Instructions & Score Sheet

**Recount**

Can you tell me what you did? How did you play the game? (Record verbatim)

*Tell me as well as show me*

*Follow up statements with ‘why?’*

---

**Retrospective memory - spontaneous rule recall**

Can you remember the 4 rules? What were they?

- 
- 
- 
- 

Try all 3 games before the sand runs out.
Yellow get more points than blue.
You get extra bonus points for every thing you fill up.
One in your hand.
Appendix 1: Battersea Multitask Paradigm Administration Instructions & Score Sheet

**Retrospective memory - cued rule recall**

How many games were there? (3)

What was special about yellow things? (More points/ than blue)

How many of the games should you have tried? (All/ 3)

How long did you have to play the games? (3 mins/ until the sand/ time runs out)

Do you think you could have finished all of the games before the sand ran out? (No)

When did the game stop? (After 3 mins/ when the sand/ time ran out)

Can you have more than one thing in your hand? (No)

Why should you go as quickly as you can? (To get lots of points/ before the time ran out)

Why should you try to fill up squares and caterpillars and pots? (To get extra bonus points)

<table>
<thead>
<tr>
<th>Count</th>
<th>Caterpillars</th>
<th>Counters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>Y-Beads</td>
<td>Yellow (Full/ Not full)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blue (Full/ Not full)</td>
</tr>
<tr>
<td></td>
<td>B-Beads</td>
<td>Y-short</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B-short</td>
</tr>
<tr>
<td></td>
<td>Y-Counters</td>
<td>Y-short</td>
</tr>
<tr>
<td></td>
<td>B-Counters</td>
<td>B-short</td>
</tr>
<tr>
<td></td>
<td>Y-Caterpillars</td>
<td>Y-med/short</td>
</tr>
<tr>
<td></td>
<td>B-Caterpillars</td>
<td>B-med/short</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Y-long</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B-long</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Beads</th>
<th>Counters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-Beads</td>
<td>Yellow (Full/ Not full)</td>
</tr>
<tr>
<td>B-Beads</td>
<td>Blue (Full/ Not full)</td>
</tr>
<tr>
<td>Y-Counters</td>
<td>Y-tall</td>
</tr>
<tr>
<td>B-Counters</td>
<td>B-tall</td>
</tr>
<tr>
<td>Y-Caterpillars</td>
<td>Y-square</td>
</tr>
<tr>
<td>B-Caterpillars</td>
<td>B-square</td>
</tr>
<tr>
<td>Y-rectangle</td>
<td>Y-rectangle</td>
</tr>
<tr>
<td>B-rectangle</td>
<td>B-rectangle</td>
</tr>
<tr>
<td>Y-large</td>
<td>Y-large</td>
</tr>
<tr>
<td>B-large</td>
<td>B-large</td>
</tr>
<tr>
<td>Full Y:</td>
<td>Full B:</td>
</tr>
</tbody>
</table>
## Battersea Multitask Paradigm – Score Sheet

<table>
<thead>
<tr>
<th>Name:</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date tested:</td>
<td>DOB:</td>
</tr>
<tr>
<td>Video Code:</td>
<td>SPSS Code:</td>
</tr>
</tbody>
</table>

### Rule Learning Score

<table>
<thead>
<tr>
<th>Free Recall Score</th>
<th>Try all 3 games before the sand runs out (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yellow things get more points than blue (1/2)</td>
</tr>
<tr>
<td></td>
<td>Filling up gets extra points (1/2)</td>
</tr>
<tr>
<td></td>
<td>One thing in your hand (1/2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Free recall total</th>
<th>Score out of 8</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Cued recall score</th>
<th>How many games are there? (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>What is special about yellow things? (1/2)</td>
</tr>
<tr>
<td></td>
<td>How many games should you try? (1)</td>
</tr>
<tr>
<td></td>
<td>How long do you have to try? (1)</td>
</tr>
<tr>
<td></td>
<td>Finish before sand runs out? (1)</td>
</tr>
<tr>
<td></td>
<td>When does the game stop? (1)</td>
</tr>
<tr>
<td></td>
<td>More than one thing in your hand? (1)</td>
</tr>
<tr>
<td></td>
<td>Why go as fast as you can? (1)</td>
</tr>
<tr>
<td></td>
<td>Why try to fill up? (1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cued recall total</th>
<th>Score out of 10</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Rule learning summed score</th>
<th>Free recall total + cued recall total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Score out of 18</td>
</tr>
</tbody>
</table>

### Planning Score

<table>
<thead>
<tr>
<th>Plan task score</th>
<th>Beads (1/2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Caterpillars (1/2)</td>
</tr>
<tr>
<td></td>
<td>Counters (1/2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plan task score total</th>
<th>Score out of 6</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Plan yellow score</th>
<th>Beads (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Caterpillars (1)</td>
</tr>
<tr>
<td></td>
<td>Counters (1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total plan yellow score</th>
<th>Score out of 3</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Plan fill score</th>
<th>Beads (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Caterpillars (1)</td>
</tr>
<tr>
<td></td>
<td>Counters (1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total plan fill score</th>
<th>Score out of 3</th>
</tr>
</thead>
</table>

### Planning score

<table>
<thead>
<tr>
<th>Planning score</th>
<th>Sum all the planning scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Score out of 12</td>
</tr>
</tbody>
</table>
### Multitask Performance Score

<table>
<thead>
<tr>
<th>Performance Variable</th>
<th>Task</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task attempt score</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td>(1 point for each task attempted)</td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Score out of 3</td>
<td></td>
</tr>
<tr>
<td>Yellow item first</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td>(1 point for single yellow item played first on each subtask)</td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Score out of 3</td>
<td></td>
</tr>
<tr>
<td>Small item first</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td>(2 points for smallest, 1 point for medium, 0 points for large)</td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Score out of 6</td>
<td></td>
</tr>
<tr>
<td>Fill item first</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td>(1 point if the first item attempted is full before proceeding)</td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Score out of 6</td>
<td></td>
</tr>
<tr>
<td>Number of small yellow items complete</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td>(Bd: tall/sq/rect); (Ct: 4/3); (Cn: 4x1/3x1)</td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Score out of 3</td>
<td></td>
</tr>
<tr>
<td>Prioritise yellow? = Binomial formula</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td>Y&gt;B = award 1 point for each task</td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td>Y&lt;B = award 1 point for each task upon which all small Y full</td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Score out of 3</td>
<td></td>
</tr>
<tr>
<td>Total Positive Performance Score</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Score out of 18</td>
<td></td>
</tr>
<tr>
<td>Error score (score 1 negative point for each task on which an item is</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td>placed in the wrong container)</td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Score out of -3</td>
<td></td>
</tr>
<tr>
<td>Rule break score (score 1 negative point for each task on which a</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td>child breaks the 1-in-your-hand-rule)</td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Score out of -3</td>
<td></td>
</tr>
<tr>
<td>Total Penalty Performance Score</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Score 0 to -6</td>
<td></td>
</tr>
<tr>
<td>Number of task switches</td>
<td>0-?</td>
<td></td>
</tr>
<tr>
<td>Task switch score</td>
<td>Score -2 or +2</td>
<td></td>
</tr>
<tr>
<td>(switches &lt;3 score -2, task switches ?? score +2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multitask Strategy Score (+ve -ve + switch)</td>
<td>Score 0 - 20</td>
<td></td>
</tr>
</tbody>
</table>
### Plan Following Score

<table>
<thead>
<tr>
<th>Score Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following plan task score</td>
<td>Plan task score (as above, out of 6)</td>
</tr>
<tr>
<td></td>
<td>Beads not performed (-1)</td>
</tr>
<tr>
<td></td>
<td>Caterpillars not performed (-1)</td>
</tr>
<tr>
<td></td>
<td>Counters not performed (-1)</td>
</tr>
<tr>
<td>Total following plan task score</td>
<td>Score range 0 to 6</td>
</tr>
<tr>
<td>Plan order score</td>
<td>Plan order score (as above, out of 6)</td>
</tr>
<tr>
<td></td>
<td>Order Planned:</td>
</tr>
<tr>
<td></td>
<td>Order performed:</td>
</tr>
<tr>
<td></td>
<td>Different order or omissions (-1 for each)</td>
</tr>
<tr>
<td>Total following plan order score</td>
<td>Score range 0 to 6</td>
</tr>
<tr>
<td>Following plan yellow score</td>
<td>Plan Yellow Score (as above, out of 3)</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for yellow beads not prioritised</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for yellow caterpillars not prioritised</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for yellow counters not prioritised</td>
</tr>
<tr>
<td>Total following plan yellow score</td>
<td>Score range 0 to 3</td>
</tr>
<tr>
<td>Following plan fill score</td>
<td>Plan fill score (as above, out of 3)</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for beads not full first</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for caterpillars not full first</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for counters not full first</td>
</tr>
<tr>
<td>Total plan fill score</td>
<td>Score range 0 to 3</td>
</tr>
<tr>
<td>Plan following score</td>
<td>Sum all the plan following scores</td>
</tr>
<tr>
<td></td>
<td>Score range 0 to 12</td>
</tr>
</tbody>
</table>

### Recount Score

<table>
<thead>
<tr>
<th>Score Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task number score</td>
<td>Beads (1/2)</td>
</tr>
<tr>
<td></td>
<td>Caterpillars (1/2)</td>
</tr>
<tr>
<td></td>
<td>Counters (1/2)</td>
</tr>
<tr>
<td>Total recount task number score</td>
<td>Score range 0 to 6</td>
</tr>
<tr>
<td>Task order score</td>
<td>Order performed:</td>
</tr>
<tr>
<td></td>
<td>Order recalled:</td>
</tr>
<tr>
<td>Total task order score</td>
<td>Score out of 3 (where they match)</td>
</tr>
<tr>
<td>Recount Summed Score</td>
<td>Sum recount scores (range 0 to 9)</td>
</tr>
</tbody>
</table>
## Rule Memory Score

<table>
<thead>
<tr>
<th>Rule memory free recall score</th>
<th>Try all 3 games before the sand runs out (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yellow things get more points than blue (1/2)</td>
</tr>
<tr>
<td></td>
<td>Filling up gets extra points (1/2)</td>
</tr>
<tr>
<td></td>
<td>One thing in your hand (1/2)</td>
</tr>
<tr>
<td>Rule memory free recall total</td>
<td>Score out of 8</td>
</tr>
<tr>
<td>Rule memory cued recall score</td>
<td>How many games are there? (1)</td>
</tr>
<tr>
<td></td>
<td>What is special about yellow things? (1/2)</td>
</tr>
<tr>
<td></td>
<td>How many games should you try? (1)</td>
</tr>
<tr>
<td></td>
<td>How long do you have to try? (1)</td>
</tr>
<tr>
<td></td>
<td>Finish before sand runs out? (1)</td>
</tr>
<tr>
<td></td>
<td>When does the game stop? (1)</td>
</tr>
<tr>
<td></td>
<td>More than one thing in your hand? (1)</td>
</tr>
<tr>
<td></td>
<td>Why go as fast as you can? (1)</td>
</tr>
<tr>
<td></td>
<td>Why try to fill up? (1)</td>
</tr>
<tr>
<td>Rule memory cued recall total</td>
<td>Score out of 10</td>
</tr>
<tr>
<td>Rule memory score</td>
<td>Free recall total + cued recall total</td>
</tr>
<tr>
<td></td>
<td>Score out of 18</td>
</tr>
<tr>
<td>Additional scores</td>
<td>Frequency of rule breaks</td>
</tr>
<tr>
<td></td>
<td>Number of task switches</td>
</tr>
<tr>
<td></td>
<td>Number of timer checks</td>
</tr>
<tr>
<td>WISC Scores</td>
<td>Vocab. (raw/ scaled):</td>
</tr>
<tr>
<td></td>
<td>Blocks (raw/ scaled):</td>
</tr>
<tr>
<td>Additional Comments:</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 2

Battersea Multitask Paradigm

Scoring Manual

Authors
Rachael Mackinlay
Tony Charman
Annette Karmiloff-Smith

Institute of Child Health, UCL
(October 2002)
Rule Learning Score

A measure of the child's initial rule learning is important as we must take into account how well the child was able to learn the rules in the first place when we are judging their performance. The child's rule learning is assessed in two ways: by free recall and cued recall. These two scores are added together to give an overall rule learning score.

Free recall score
Score the child's free recall of the rules. This is recorded verbatim from the video. Score 2 points for each rule correctly recalled. Four rules so the maximum score is 8 points.

- You must try all 3 games before the sand/time runs out 2
- Yellow things get more points than blue (beads, caterpillars & counters) 1/2*
- Filling up gets extra points (pots, caterpillars & squares) 1/2*
- One thing in your hand at a time (beads, crayons & counters) 1/2*

Max: 8

*For these rules score 2 for generic rules (you get more points for filling things up/ yellow things etc. Score 1 point if specific items are mentioned, e.g. you get more points for yellow beads/ you can only take one token at a time/ you get extra points for filling up pots. Or score 1 for saying yellow gets more points (but no mention of yellow relative to blue).

Cued recall score
The child responds to cued questions about the tasks and the rules governing their performance. One point is awarded for each correct answer, there are nine questions & the maximum score is 10:

- How many games are there? (3) 1
- What is special about yellow things? (More points than blue) 1/2*
- How many of the games should you try? (All/ 3) 1
- How long do you have to play the games? (Until the sand/time runs out) 1
- Do you think you could finish any of the games before the sand runs out? (No) 1
- When does the game stop? (When the sand/time runs out) 1
- Can you have more than one thing in your hand? (No) 1
- Why should you go as quickly as you can? (To get lots of points/ before time runs out) 1
- Why should you try to fill up a square or a caterpillar or a pot? (To get extra points) 1

Max: 10

*Score 1 for saying yellow gets more points (but no mention of yellow relative to blue).

Rule learning score is therefore scored out of a maximum of 18 points.
Appendix 2: Battersea Multitask Paradigm Scoring Manual

Planning Score

This is to measure the validity of the child’s initial plan. The planning score is divided into three parts. The child’s plan is recorded verbatim from the video.

Plan task score
Points are awarded for each task planned. This can be implicit or explicit, e.g. “I'll do a bit of each” or “I'll do some beads, then some of these (pointing is ok) then some of these.” 2 points are given for each task for which a plan was spontaneously offered.

Many children required prompting to achieve a plan including all 3 tasks. We believed it was necessary to obtain such a plan from the children so that they clearly understood the task before performing it. Therefore children score 1 point for each task for which a plan was prompted, 2 points where they mentioned the task without prompting.

<table>
<thead>
<tr>
<th>Task</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beads</td>
<td>1/2</td>
</tr>
<tr>
<td>Caterpillars</td>
<td>1/2</td>
</tr>
<tr>
<td>Counters</td>
<td>1/2</td>
</tr>
<tr>
<td>Max:</td>
<td>6</td>
</tr>
</tbody>
</table>

Plan yellow score
Any mention of the child’s intent to prioritise yellow items is rewarded points. This shows evidence of relatively sophisticated strategy use in that the children are planning for efficiency as yellow items earn more points. The plan to do yellow can be a general statement, such as “I’ll do yellow” which scores 3 points. A plan to prioritise yellow on one task scores one point, e.g., “I'll do yellow beads.”

<table>
<thead>
<tr>
<th>Intent to prioritise yellow items</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>on all three tasks</td>
<td>3</td>
</tr>
<tr>
<td>on two of the tasks</td>
<td>2</td>
</tr>
<tr>
<td>on one task</td>
<td>1</td>
</tr>
<tr>
<td>Max:</td>
<td>3</td>
</tr>
</tbody>
</table>

Plan fill score
Any mention of the child’s intent to prioritise filling items is rewarded points. This shows evidence of relatively sophisticated strategy use in that the children are planning for efficiency as filling things up earns extra points. Note that planning to fill items usually involves selecting the smallest pots, shortest caterpillars or smallest squares. A plan to fill an item is a verbal demonstration of intent to fill up an item on a task e.g. “I’ll fill one up…” and is recorded from the child’s verbal plan on video.

<table>
<thead>
<tr>
<th>Intent to prioritise filling items</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>on all three tasks</td>
<td>3</td>
</tr>
<tr>
<td>on two of the tasks</td>
<td>2</td>
</tr>
<tr>
<td>on one task</td>
<td>1</td>
</tr>
<tr>
<td>Max:</td>
<td>3</td>
</tr>
</tbody>
</table>

Planning score is therefore scored out of a maximum of 12 points.
Appendix 2: Battersea Multitask Paradigm Scoring Manual

Multitask Performance Score

This is a measure of overall task success. The composite multitask performance score is composed of 3 scores. (1) The strategic performance score is derived from the child’s performance in terms of the number of tasks performed and the use of successful strategies to maximise their score. (2) The penalty performance score is scored when points are subtracted for rule breaking or incorrectly placed items. (3) The task switch score is scored as the number of times a child switches between tasks.

[a] Strategic performance score

Task attempt score
One point is awarded for each individual subtask attempted:

<table>
<thead>
<tr>
<th>Task</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beads</td>
<td>1</td>
</tr>
<tr>
<td>Caterpillars</td>
<td>1</td>
</tr>
<tr>
<td>Counters</td>
<td>1</td>
</tr>
</tbody>
</table>

Max: 3

Yellow item first
This score is designed to check that children prioritise yellow items on each of the 3 tasks. If the first item placed on a task is yellow, children score 1 point for ‘yellow first’ on that task:

<table>
<thead>
<tr>
<th>Task</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beads</td>
<td>1</td>
</tr>
<tr>
<td>Caterpillars</td>
<td>1</td>
</tr>
<tr>
<td>Counters</td>
<td>1</td>
</tr>
</tbody>
</table>

Max: 3

Small item first
This score is designed to check whether children prioritise smaller items on each task. Points are awarded depending on the size of the first item children attempt to fill on each task.

<table>
<thead>
<tr>
<th>Item size</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small item</td>
<td>2</td>
</tr>
<tr>
<td>Medium item</td>
<td>1</td>
</tr>
<tr>
<td>Large item</td>
<td>0</td>
</tr>
</tbody>
</table>

For each subtask therefore Max: 6 (if small item attempted first on each task)

Fill item first
This score similarly checks whether children are prioritising the ‘fill’ rule – points are awarded if children fill the first item they begin on a task before proceeding to another one (e.g. fill a pot of beads before moving on to caterpillars). One point is awarded for each task on which children fill the first item.

<table>
<thead>
<tr>
<th>Task</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beads</td>
<td>1</td>
</tr>
<tr>
<td>Caterpillars</td>
<td>1</td>
</tr>
<tr>
<td>Counters</td>
<td>1</td>
</tr>
</tbody>
</table>

Max: 3

Number of small yellow items complete & prioritise yellow score
These two scores are designed to assess whether children have prioritised the ‘yellow’ rule. Note that the ‘yellow’ rule trades off against the ‘fill’ rule. Children who are aware of the trade off between gaining more points for choosing yellow items versus earning bonus points for filling small items may reflect this in their performance. Adults generally choose to fill small yellow items first and may then either progress to fill medium yellow items or begin filling small blue items. The point is that by thinking about this trade-off, participants are truly multitasking, weighing up options and making decisions based upon the alternatives.

Scoring performance in light of this trade off is complicated. We elected to determine whether children had placed more yellow items than blue items on a task using a binomial formula (see below). In cases where participants had not placed significantly more yellow items than blue, we looked at whether they had filled all the small yellow items on the task (which
would indicate the trade off between yellow items and filling items). If all small yellow items are completed – the participant is deemed to have prioritised yellow items on that task, irrespective of whether the actual number of yellow items placed is significantly more than the number of blue items placed.

Scoring is therefore achieved in the following way:

**Number of small yellow items completed (must be all to score 1 point for that task):**

- **Beads (tall container, two square containers)**: - score 1 (if all 3 full)
- **Caterpillars (Two shortest are 4 circles long)**: - score 1 (if both full)
- **Counters (Two 4x1 squares, One 3x1 square)**: - score 1 (if all 3 full)

**Prioritise yellow – Binomial formula**

This formula assesses whether children place a significantly greater number of yellow items than blue on each task. One point is awarded for each task on which yellow items significantly outnumber blue items. The significance (beyond chance) is calculated by a binomial formula relating to the number of items placed, the number of items of each colour and number of options (e.g. 2 colour options).

- **Beads**: \( Y > B \) = 1
- **Caterpillars**: \( Y > B \) = 1
- **Counters**: \( Y > B \) = 1

Binomial formulae decision trees and value tables are included in the appendix at the back of this manual.

The number of small yellow items complete & prioritise yellow scores are added together (see scoring sheet) so that only 1 point is awarded per task for prioritising yellow items. The score is calculated on the basis of either/or (either \( Y \) sig. > \( B \), or all small \( Y \) full).

The overall maximum for these two scores = 3

**Therefore strategic performance is scored out of a maximum of 18 points.**

[b] **Penalty performance score**

**Error score**

Score one penalty point for each task on which the child makes an error. An error is colouring a caterpillar in the wrong colour, putting the wrong bead into the wrong pot, or placing the wrong colour of counter onto a square.

- **Beads**: -1
- **Caterpillars**: -1
- **Counters**: -1

**Max**: -3

**Rule break score**

Score one penalty point for each task on which the child breaks the ‘one in your hand’ rule:

- **Beads**: -1
- **Caterpillars**: -1
- **Counters**: -1

**Max**: -3

**Therefore penalty performance is scored out of a maximum of 6 points.**
Appendix 2: Battersea Multitask Paradigm Scoring Manual

[3] Task switch score

This score was designed to evaluate the number of times a participant switches tasks during performance. The lower limit of the number of task switches is set at 3. This means that a participant must not only perform the necessary 2 switches to have attempted all 3 tasks, but that they must have returned to at least one other task (to stay fixed on the 3rd task is not true multitasking). The upper limit was determined by the peer group of the participant. Some participants placed only one item on each task, switching between them constantly during play generating a large number of switches (35 etc.). This strategy was inefficient as it did not involve taking account of the rules such as the 'fill' rule. All task switches above 3 and below the group determined upper limit were deemed efficient.

Points are awarded for task switch score as follows:

Switches \( \leq 2 \) score -2 points
Switches \( \geq 3 \) but \( < x \) score +2 points

Multitask Performance Score is calculated as:

\[
\text{Positive performance score max} + 18 \\
+ \quad \text{Penalty performance score max} - 6 \\
+ \quad \text{Task switch score} \quad -2 \text{ or } +2 \\
= \quad \text{Multitask Performance Score: max} + 20
\]
Plan Following Score

This score reflects the extent to which the children followed their original plan. The overall score is derived from the sum of the following plan task score, the following plan yellow score and the following plan fill score. These scores are tied to the initial plan and the actual performance.

Following plan task score

We evaluate whether children performed the number of tasks they planned to perform, and whether they performed them in the order they planned. We were interested to see if children performed the tasks in the order in which they had planned as performing the tasks in a different order may reflect a lack of 'remembering to remember' if the initial plan was discarded. The score is calculated as:

- Plan task score calculated previously \((\text{max. } 6\text{ points})\)
- subtract 1 point for each task not performed \((\text{max. } -3\text{ points})\)
- subtract 1 point for each discrepancy in order performed versus order planned \((\text{max } -3\text{ points})\)

To calculate plan order: compare the order of tasks planned with the order of tasks performed. Subtract 1 point for each task performed in a different order from that in which they were planned:

Planned: Beads – Counters – Caterpillars
Performed: Beads – Caterpillars – Counters

Score: – 2 as two tasks in discrepant order

Therefore following plan task score will have a maximum of +6 points.

Following plan yellow score

If the children planned for greater yellow items – did their performance reflect this?

- Plan yellow score as calculated previously \((\text{max } +3\text{ points})\)
- Yellow > Blue score subtract 1 point for each task where yellow is not prioritised \((\text{max } -3\text{ points})\)

Therefore following plan yellow score has a maximum of +3 points.

If the participant did not generate an initial 'plan yellow' – plan following score is automatically 0.

Following plan fill score

If the children planned to fill items did their performance reflect this? We calculate whether filling was a priority on the basis of the 'fill item first' score.

- Plan fill score as calculated previously \((\text{max } +3\text{ points})\)
- Fill item first score subtract 1 point for each task where item is not filled first \((\text{max } -3\text{ points})\)

Therefore following plan fill score has a maximum of +3.

If the participant did not generate an initial 'plan fill' – plan following score is automatically 0.

Therefore plan following is scored out of a maximum of +12 points.
Recount Score

This is a self-monitoring exercise to check that the child is aware of approximately what they achieved during task performance.

Task number score
Score 2 points for each task correctly (& spontaneously) recalled as having been performed. Only 1 point is awarded for each task on which the participant had to be prompted to explain what they had done.

Task number score is scored out of a maximum of 6 points.

Task order score
Score one point for each task recounted in the order in which it was performed:
Performance order: Beads – Caterpillars – Counters
Recount order: Beads – Counters – Caterpillars
(scores 1 point for beads recounted in correct order).

Task order score is scored out of a maximum of 3 points.

Recount score is therefore scored out of a maximum of +9 points.
Appendix 2: Battersea Multitask Paradigm Scoring Manual

Rule Memory Score

This score checks whether children can remember the rules of the game. If they cannot remember the rules - how can they 'remember to remember' to obey them? Rule memory is scored in the same way as the rule learning score.

Rule Memory - free recall score

Score the child's retrospective free recall of the rules. This is recorded verbatim from the video. Score 2 points for each rule correctly recalled. Four rules so the maximum score is 8 points.

- You must try all 3 games before the sand/time runs out 2
- Yellow things get more points than blue (beads, balloons & tokens) 1/2*
- Filling up gets extra points 1/2*
- One thing in your hand at a time (beads, crayons & tokens) 1/2*

Max: 8

*For these rules score 1 if specific items are mentioned rather than generic rules, e.g. you get more points for yellow beads/you can only take one token at a time/you get extra points for filling up beads. Or score 1 for saying yellow gets more points (but no mention of yellow relative to blue).

Rule memory - cued recall score

The child responds to cued questions about the tasks and the rules governing their performance. One point is awarded for each correct answer, there are nine questions & the maximum score is 10:

- How many games are there? (3) 1
- What is special about yellow things? (More points than blue) 1/2*
- How many of the games should you try? (All/ 3) 1
- How long do you have to play the games? (Until the sand/time runs out) 1
- Do you think you could finish any of the games before the sand runs out? (No) 1
- When does the game stop? (When the sand/time runs out) 1
- Can you have more than one thing in your hand? (No) 1
- Why should you go as quickly as you can? (To get lots of points/ before time runs out) 1
- Why should you try to fill up a square or a caterpillar or a pot? (To get extra points) 1

Max: 10

*Score 1 for saying yellow gets more points (but no mention of yellow relative to blue).

Rule Memory is therefore scored out of a maximum of +18 points.
Appendix 2: Battersea Multitask Paradigm Scoring Manual

Binomial Formulae Decision Tree

Is there as significant difference between observed and expected number of yellow items in multitask performance? Is there a significant difference between observed and expected proportions in a series of dichotomous observations?

H₁ Experimental hypothesis: significant difference, greater number of yellow items than chance
H₀ Null Hypothesis: no significant difference, number of yellow items expected by chance

First calculate total N (total number of items placed on individual task: yellow + blue items)

N \leq 35

N = total number items placed (both observed frequencies, yellow + blue)
K = smaller of the observed frequencies

Refer to table D: calculate P for knowing the values of N and K.

*Note the direction of H₁ is 1-tailed.

N > 35

N = total number items placed (both observed frequencies, yellow + blue)
Y = smaller of the observed frequencies
p = 0.5
q = 0.5
Np = N x p (i.e. N x 0.5)

Calculate z-value using the formula below:

\[ Z = \frac{(Y +/- 0.5) - Np}{\sqrt{Npq}} \]

Y + 0.5 where Y < Np
Y - 0.5 where Y > Np

Refer to Table A for significance levels of z-value to the nearest decimal point.

*Note the direction of H₁ is 1-tailed & that significance level has been set at 1%
Table D: Table of probabilities associated with values as small as (or smaller than) observed values of k in the binomial test

*Given in the body of the table are one-tailed probabilities under $H_0$ for the binomial test where $p = q = \frac{1}{2}$*

Entries are $P[Y \leq k]$. Note that entries may also read as $P[Y \geq N-k]$
Appendix 3

Multitask Training Study

Administration Instructions

&

Score Sheet
Appendix 3: Multitask Training Study Administration Instructions & Score Sheet

(Training Study - 1)

Name: ________________________________________________________
Date: ________________________________________________________
School: _______________________________________________________
Year: _________________________________________________________
Video Code: ___________________________________________________

DOB ___________________________  E: ____________________________
Age: ___________________________  Gender: _________________________
SPSS: ____________________________

What colour is this?

Yellow –
Blue –

Handedness
Appendix 3: Multitask Training Study Administration Instructions & Score Sheet

Introduction
• Here are three games
• In each game you can get points
• First I'm going to teach you how to play the games one at a time
• Then you are going to play them all at the same time

Counters
This game is called counters. Here are counters to sort out - you put them in these squares.
(Place two blue counters in the blue square, and two yellow counters in the yellow square, taking care to place counters one-by-one).

A blue counter goes on blue like this...

A yellow counter goes on yellow like this...

You try to fill up this square.

Watch to check that the child is placing the counters in the correct squares, and picking them up one-by-one. Once the child has filled both practice squares, say:

Remember I told you that you score points in these games? There are two good ways to score points:

The first is to fill up the squares. For each square you fill, you get lots of extra bonus points. It's good to fill squares. This square is all filled up (demonstrate), so you get lots of extra bonus points. This square is not filled up (demonstrate by removing a counter from a practice square), so you don't get extra bonus points for it.

The other good way to score points is to remember something special about the colour yellow. In this game, yellow things are worth more points than blue. It is a good idea to use a lot of yellow things when you play this game, because yellow things are worth more points than blue (demonstrate by holding yellow counter in the air higher than a blue counter).

Remember then, yellow things are worth more points than blue, and full squares, yellow or blue, score lots of extra bonus points.

Beads
This game is called beads. Here are beads to sort out - you put them in these pots. (Place some blue beads in the blue pot, and some yellow beads in the yellow pot, taking care to place them one-by-one).

Blue beads go into the blue pot like this...

Yellow beads go into the yellow pot like this...

Remember you can only pick them up one by one.

You try. Watch to check that the child is placing the beads in the correct coloured pots, and picking them up one-by-one. Once the child has tried a few of each, say:

Let's fill up the yellow pot so that you can see what a full pot looks like, I'll help you. (Fill up the yellow pot with the child...)

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Good. Now, do you remember I told you the two good ways to score points in these games?

If the child remembers, affirm what he/she is saying. If the child looks blank, say the point scoring rules again. Either way, you say the rules to the child using the phrases below.

The first way to score lots of points is to fill things up. Just like you scored extra bonus points for filling up squares (gesture to counters game), in the beads game you score extra bonus points for filling up a whole pot. This pot is all filled up (demonstrate), so you get lots of extra bonus points. This pot is not filled up (demonstrate the blue pot which is not full), so you don’t score extra bonus points for it.

You get extra bonus points for every pot you fill, yellow or blue, remember then, filling up pots is a good idea.

The other good way to score points is to remember something special about the colour yellow. In this game, yellow things are worth more points than blue. It is a good idea to use a lot of yellow things when you play, because yellow things are worth more points than blue (demonstrate by holding yellow bead in the air higher than a blue bead).

Remember then, yellow things are worth more points than blue, and full pots, yellow or blue, score lots of extra bonus points.

**Caterpillars**

This game is called caterpillars. Here are caterpillars to colour in. What colour should this caterpillar be? (Point to the blue caterpillar)

I’ll colour this one in (demonstrate by colouring in the blue caterpillar). Whilst colouring illustrate that the child should only colour circles one-by-one. Also illustrate that the circle should be mostly covered, and that messy colouring is OK. Use the following phrases:

You should only colour the circles in one-by-one, just like you picked up the beads and counters one-by-one.

I’m a bit of a messy person colouring in (go over the sides of the circle as you say this), so it’s OK if you are too...

You should cover all of the circle (demonstrate by colouring half a circle), so this is not enough colouring – you should colour all of the circle (demonstrate).

What colour should this caterpillar be? You colour it in.

Watch to check that the child is colouring one circle at a time, and covering most of each circle.

Good. Now, can you tell me what you get if you fill a whole caterpillar up? (affirm the child’s response if correct, if not repeat the rule, either way say the rule again using the following phrases)

Filling up a whole caterpillar gets you lots of extra bonus points. So this caterpillar is full, and this caterpillar is full, so you get lots of extra bonus points for each one.

And, do you remember what is special about yellow things in this game? (affirm the child’s response if correct, if not repeat the rule, either way say the rule again)

Remember then, yellow things are worth more points than blue, and full things, yellow or blue, score lots of extra bonus points.

Once the practice session is finished remove practice materials from the table and place the 3 tasks of the Battersea Multitask Paradigm on the table in front of the child (arranged in the same order as the practice tasks)
‘The game’

Now you know how to play the 3 games. Here’s how we play all 3 games at the same time:

- Look at this timer
- This is how much time you have to try all 3 games
- It is not very long – only 3 minutes
- The game starts when I turn over the timer like this and the sand goes from the top to the bottom
- The game stops when all the sand has reached the bottom of the timer

- Before you play, you have to learn the rules.

Rules

There are 4 rules:

- Before the sand has gone from the top to the bottom, you must try all 3 games -- some beads, some caterpillars and some counters. You can’t miss out any of them. You have to try all 3.

- You won’t be able to finish any of them, so don’t try to. There are too many beads to sort out. There are too many caterpillars to colour in. There are too many counters to place.
- You just have to try all 3 games.

- You get more points for yellow than blue. Don’t forget then, yellow gives you more points, you should do more yellow things.

- You get extra bonus points for every pot, caterpillar or square you fill up. You should fill up the things you do.

- Only one thing in your hand at a time. One bead, one crayon or one counter. So, only one in your hand, not two (demonstrate by holding more than one bead in your hand).

You must not break the rules.
Appendix 3: Multitask Training Study Administration Instructions & Score Sheet

You need to remember these 4 rules because I am going to ask you what they are. Listen carefully and say them right after me (get participant to repeat each rule after you):

- Try all 3 games before the sand runs out.
- Yellow gets more points than blue.
- You get extra/bonus points for every thing you fill up.
- One thing in your hand at a time.

Repetition free recall rule learning (1)
Now - can you tell me the 4 rules?

- 
- 
- 
- 

That's very good. I will say the rules again. Listen carefully and say them right after me (get child to repeat each rule after you):

Try all 3 games before the sand runs out.

Yellow gets more points than blue.

You get extra/bonus points for every thing you fill up.

One thing in your hand at a time.

Repetition free recall rule learning (2)
Now - can you tell me the 4 rules?

- 
- 
- 
- 

That's very good. I will say the rules again. Listen carefully and say them right after me (get child to repeat each rule after you):

- Try all 3 games before the sand runs out.
- Yellow gets more points than blue.
You get extra bonus points for every thing you fill up.

One thing in your hand at a time.

Repetition free recall rule learning (3)
Now - can you tell me the 4 rules?

Cued rule learning

How many games are there? (3)

What is special about yellow things? (More points than blue)

How many of the games should you try? (All/3)

How long do you have to play the games? (3 mins./until the sand/time runs out)

Do you think you could finish all of the games before the sand runs out? (No)

When does the game stop? (After 3 mins./when the sand/time runs out)

Can you have more than one thing in your hand? (No)

Why should you go as quickly as you can? (Get lots of points/before time runs out/fill things up)

Why should you try to fill up squares and caterpillars and pots? (To get extra/bonus points)
Appendix 3: Multitask Training Study Administration Instructions & Score Sheet

Planning

I want you to get as many points as you can. How will you play the game to get as many points as you can? (Record verbatim)

*Tell me as well as show me

*Note where a plan is prompted by putting a (P) next to the prompted comment.

Well done – now we're ready to play. Remember to get as many points as you can:

- Try all 3 games before the sand runs out.
- Yellow gets more points than blue.
- You get extra bonus points for every thing you fill up.
- One thing in your hand at a time.
Performance

Keep an eye on the timer – I don’t want it to stop before you have tried ALL 3 games.

Ready...steady...GO!

(Turn over timer and start stopwatch)

<table>
<thead>
<tr>
<th>Time started</th>
<th>Task: Bd/Cat/Cn</th>
<th>Items placed/completed</th>
<th>Rule breaks?</th>
<th>Switch time</th>
<th>Time Checks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

Stop! (Recount and Rule Memory)
Appendix 3: Multitask Training Study Administration Instructions & Score Sheet

Recount

Can you tell me what you did? How did you play the game? (Record verbatim)

*Tell me as well as show me

*Follow up statements with ‘why?’

Rule Memory – free recall

Can you remember the 4 rules? What were they?

•

•

•

•

Try all 3 games before the sand runs out.
Yellow get more points than blue.
You get extra bonus points for every thing you fill up.
One in your hand.
Appendix 3: Multitask Training Study Administration Instructions & Score Sheet

**Rule Memory – cued recall**

- How many games were there? (3)
- What was special about yellow things? (More points than blue)
- How many of the games should you have tried? (All 3)
- How long did you have to play the games? (3 mins. until the sand time runs out)
- Do you think you could have finished all of the games before the sand ran out? (No)
- When did the game stop? (After 3 mins when the sand time ran out)
- Can you have more than one thing in your hand? (No)
- Why should you go as quickly as you can? (To get lots of points before the time ran out)
- Why should you try to fill up squares and caterpillars and pots? (To get extra bonus points)

<table>
<thead>
<tr>
<th>Count</th>
<th>Caterpillars</th>
<th>Counters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yellow (Full/ Not full)</td>
<td>Blue (Full/ Not full)</td>
</tr>
<tr>
<td>Y-Beads</td>
<td>B-Beads</td>
<td></td>
</tr>
<tr>
<td>Y-Counters</td>
<td>B-Counters</td>
<td></td>
</tr>
<tr>
<td>Y-Caterpillars</td>
<td>B-Caterpillars</td>
<td></td>
</tr>
<tr>
<td>Beads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow (Full/ Not full)</td>
<td>Blue (Full/ Not full)</td>
<td></td>
</tr>
<tr>
<td>Y-tall</td>
<td>B-tall</td>
<td></td>
</tr>
<tr>
<td>Y-square</td>
<td>B-square</td>
<td></td>
</tr>
<tr>
<td>Y-rectangle</td>
<td>B-rectangle</td>
<td></td>
</tr>
<tr>
<td>Y-large</td>
<td>B-large</td>
<td></td>
</tr>
<tr>
<td>Full Y</td>
<td>Full B</td>
<td></td>
</tr>
<tr>
<td>Counter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow (Full/ Not full)</td>
<td>Blue (Full/ Not full)</td>
<td></td>
</tr>
<tr>
<td>Yellow 4x1</td>
<td>Blue 3x1</td>
<td></td>
</tr>
<tr>
<td>Yellow 4x1</td>
<td>Blue 3x1</td>
<td></td>
</tr>
<tr>
<td>Yellow 4x1</td>
<td>Blue 4x1</td>
<td></td>
</tr>
<tr>
<td>Yellow 3x3</td>
<td>Blue 3x3</td>
<td></td>
</tr>
<tr>
<td>Yellow 4x4</td>
<td>Blue 4x4</td>
<td></td>
</tr>
<tr>
<td>Name:</td>
<td>School</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>Date tested:</td>
<td>DOB:</td>
<td></td>
</tr>
<tr>
<td>Video Code:</td>
<td>Age:</td>
<td></td>
</tr>
</tbody>
</table>

### Rule Training Score

<table>
<thead>
<tr>
<th>Repetition 1</th>
<th>Try all 3 games before the sand runs out (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yellow things get more points than blue (1/2)</td>
</tr>
<tr>
<td></td>
<td>Filling up gets extra bonus points (1/2)</td>
</tr>
<tr>
<td></td>
<td>One thing in your hand (1/2)</td>
</tr>
<tr>
<td>Repetition 1 total</td>
<td>Score out of 8</td>
</tr>
<tr>
<td>Repetition 2</td>
<td>Try all 3 games before the sand runs out (2)</td>
</tr>
<tr>
<td></td>
<td>Yellow things get more points than blue (1/2)</td>
</tr>
<tr>
<td></td>
<td>Filling up gets extra bonus points (1/2)</td>
</tr>
<tr>
<td></td>
<td>One thing in your hand (1/2)</td>
</tr>
<tr>
<td>Repetition 2 total</td>
<td>Score out of 8</td>
</tr>
<tr>
<td>Repetition 3</td>
<td>Try all 3 games before the sand runs out (2)</td>
</tr>
<tr>
<td></td>
<td>Yellow things get more points than blue (1/2)</td>
</tr>
<tr>
<td></td>
<td>Filling up gets extra bonus points (1/2)</td>
</tr>
<tr>
<td></td>
<td>One thing in your hand (1/2)</td>
</tr>
<tr>
<td>Repetition 3 total</td>
<td>Score out of 8</td>
</tr>
</tbody>
</table>

### Score

- Repetition 1 total: Score out of 8
- Repetition 2 total: Score out of 8
- Repetition 3 total: Score out of 8
- Cued recall total: Score out of 10

### Rule learning score

Rule training total + cued recall total

### Score out of 18

404
### Planning Score

<table>
<thead>
<tr>
<th>Plan task score</th>
<th>Beads (1/2)</th>
<th>Caterpillars (1/2)</th>
<th>Counters (1/2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan task score total</td>
<td>Score out of 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan yellow score</td>
<td>Beads (1)</td>
<td>Caterpillars (1)</td>
<td>Counters (1)</td>
</tr>
<tr>
<td>Total plan yellow score</td>
<td>Score out of 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan fill score</td>
<td>Beads (1)</td>
<td>Caterpillars (1)</td>
<td>Counters (1)</td>
</tr>
<tr>
<td>Total plan fill score</td>
<td>Score out of 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning summed score</td>
<td>Sum all the planning scores</td>
<td>Score out of 12</td>
<td></td>
</tr>
</tbody>
</table>

### Plan Following Score

<table>
<thead>
<tr>
<th>Following plan task score</th>
<th>Plan task score (as above, out of 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beads not performed (-1)</td>
</tr>
<tr>
<td></td>
<td>Caterpillars not performed (-1)</td>
</tr>
<tr>
<td></td>
<td>Counters not performed (-1)</td>
</tr>
<tr>
<td>Total following plan task score</td>
<td>Score range 0 to 6</td>
</tr>
<tr>
<td>Plan order score</td>
<td>Plan order score (as above, out of 6)</td>
</tr>
<tr>
<td></td>
<td>Order Planned</td>
</tr>
<tr>
<td></td>
<td>Order performed:</td>
</tr>
<tr>
<td></td>
<td>Different order or omissions (-1 for each)</td>
</tr>
<tr>
<td>Total following plan order score</td>
<td>Score range 0 to 6</td>
</tr>
<tr>
<td>Following plan yellow score</td>
<td>Plan Yellow Score (as above, out of 3)</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for yellow beads not prioritised</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for yellow caterpillars not prioritised</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for yellow counters not prioritised</td>
</tr>
<tr>
<td>Total following plan yellow score</td>
<td>Score range 0 to 3</td>
</tr>
<tr>
<td>Following plan fill score</td>
<td>Plan fill score (as above, out of 3)</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for beads not full first</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for caterpillars not full first</td>
</tr>
<tr>
<td></td>
<td>Subtract 1 point for counters not full first</td>
</tr>
<tr>
<td>Total plan fill score</td>
<td>Score range 0 to 3</td>
</tr>
<tr>
<td>Plan following summed score</td>
<td>Sum all the plan following scores</td>
</tr>
<tr>
<td></td>
<td>Score range 0 to 12</td>
</tr>
</tbody>
</table>
# Multitask Performance Score

<table>
<thead>
<tr>
<th>Performance Variable</th>
<th>Task</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task attempt score (1 point for each task attempted)</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td>Yellow item first (1 point for single yellow item played first on each subtask)</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td>Small item first (2 points for smallest, 1 point for medium, 0 points for large)</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td>Fill item first (1 point if the first item attempted is full before proceeding)</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td>Number of small yellow items complete (Bd: tall/sq/rect), (Ct: 4/3), (Cn: 4x1/3x1)</td>
<td>Beads (1-3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caterpillars  (1-2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters (1-3)</td>
<td></td>
</tr>
<tr>
<td>Prioritise yellow? = Binomial formula Y&gt;B = award 1 point for each task</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td>Y&lt;B = award 1 point for each task upon which all small Y full</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Positive Performance Score</td>
<td>Score out of 18</td>
<td></td>
</tr>
<tr>
<td>Error score (score 1 negative point for each task on which an item is placed in the wrong container)</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td>Rule break score (score 1 negative point for each task on which a child breaks the 1-in-your-hand-rule)</td>
<td>Beads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counters</td>
<td></td>
</tr>
<tr>
<td>Total Penalty Performance Score</td>
<td>Score 0 to -6</td>
<td></td>
</tr>
<tr>
<td>Number of task switches</td>
<td>0-?</td>
<td></td>
</tr>
<tr>
<td>Task switch score (switches &lt;3 score -2, task switches &gt;? score +2)</td>
<td>Score -2 or +2</td>
<td></td>
</tr>
<tr>
<td>Multitask Strategy Score (+ve + -ve + switch)</td>
<td>Score 0 - 20</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix 3: Multitask Training Study Administration Instructions & Score Sheet

<table>
<thead>
<tr>
<th>Score Category</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recount Score</strong></td>
<td></td>
</tr>
<tr>
<td>Task number score</td>
<td>Beads (1/2)</td>
</tr>
<tr>
<td></td>
<td>Caterpillars (1/2)</td>
</tr>
<tr>
<td></td>
<td>Counters (1/2)</td>
</tr>
<tr>
<td><strong>Total recount task number score</strong></td>
<td>Score range 0 to 6</td>
</tr>
<tr>
<td><strong>Task order score</strong></td>
<td>Order performed:</td>
</tr>
<tr>
<td></td>
<td>Order recalled:</td>
</tr>
<tr>
<td><strong>Total task order score</strong></td>
<td>Score out of 3 (where they match)</td>
</tr>
<tr>
<td><strong>Recount Summed Score</strong></td>
<td>Sum recount scores (range 0 to 9)</td>
</tr>
<tr>
<td><strong>Retrospective Memory Score</strong></td>
<td></td>
</tr>
<tr>
<td>Retrospective free recall score</td>
<td>Try all 3 games before the sand runs out (2)</td>
</tr>
<tr>
<td></td>
<td>Yellow things get more points than blue (1/2)</td>
</tr>
<tr>
<td></td>
<td>Filling up gets extra points (1/2)</td>
</tr>
<tr>
<td></td>
<td>One thing in your hand (1/2)</td>
</tr>
<tr>
<td><strong>Retrospective free recall total</strong></td>
<td>Score out of 8</td>
</tr>
<tr>
<td>Retrospective cued recall score</td>
<td>How many games are there? (1)</td>
</tr>
<tr>
<td></td>
<td>What is special about yellow things? (1/2)</td>
</tr>
<tr>
<td></td>
<td>How many games should you try? (1)</td>
</tr>
<tr>
<td></td>
<td>How long do you have to try? (1)</td>
</tr>
<tr>
<td></td>
<td>Finish before sand runs out? (1)</td>
</tr>
<tr>
<td></td>
<td>When does the game stop? (1)</td>
</tr>
<tr>
<td></td>
<td>More than one thing in your hand? (1)</td>
</tr>
<tr>
<td></td>
<td>Why go as fast as you can? (1)</td>
</tr>
<tr>
<td></td>
<td>Why try to fill up? (1)</td>
</tr>
<tr>
<td><strong>Retrospective cued recall total</strong></td>
<td>Score out of 10</td>
</tr>
<tr>
<td><strong>Rule learning summed score</strong></td>
<td>Free recall total + cued recall total</td>
</tr>
<tr>
<td></td>
<td>Score out of 18</td>
</tr>
<tr>
<td><strong>Additional scores</strong></td>
<td>Frequency of rule breaks</td>
</tr>
<tr>
<td></td>
<td>Number of task switches</td>
</tr>
<tr>
<td></td>
<td>Number of timer checks</td>
</tr>
</tbody>
</table>

**Additional Comments:**
Appendix 4

Single Task Study

Administration Instructions &
Score Sheet
<table>
<thead>
<tr>
<th>Single Task</th>
<th>Beads</th>
</tr>
</thead>
</table>

Name: ____________________________
Date: ____________________________
School: ____________________________
Year: ____________________________
Video Code: ____________________________

DDB: ____________________________
Age: ____________________________
Gender: ____________________________

What colour is this?

Yellow –
Blue –

Handedness
Appendix 4: Single Task Study Administration Instructions & Score Sheet

Introduction
- Look at this game
- In this game you can get points
- First I'm going to teach you how to play the game
- Then you are going to play the game

Beads (will be used as an example here)
This game is called beads. Here are beads to sort out - you put them in these pots. (Place some blue beads in the blue pot, and some yellow beads in the yellow pot, taking care to place them one-by-one).

Blue beads go into the blue pot like this...

Yellow beads go into the yellow pot like this...

Remember you can only pick them up one by one.

You try. (Watch to check that the child is placing the beads in the correct coloured pots, and picking them up one-by-one. Once the child has tried a few of each, say...)

Let's fill up the yellow pot so that you can see what a full pot looks like, I'll help you. (Fill up the yellow pot with the child...)

Remember I told you that you score points in this game? There are two good ways to score points:

You get extra bonus points for every pot you fill, yellow or blue, remember then, filling up pots is a good idea.

The other good way to score points is to remember something special about the colour yellow. In this game, yellow beads are worth more points than blue. It is a good idea to use a lot of yellow beads when you play this game, because yellow beads are worth more points than blue (demonstrate by holding yellow bead in the air higher than a blue bead).

Remember then, yellow things are worth more points than blue, and full pots, yellow or blue, score lots of extra bonus points.
‘The game’

Here is how to play the game.

- Look at my timer – it is 1 minute long. It goes very fast.
- The game starts when I turn the timer over – and the sand starts to go from the top to the bottom. The game stops when all the sand has reached the bottom.
- You don’t have enough time to finish the whole game. I don’t want you to try.
- I do want you to get as many points as you can.
- Before you play, you have to learn the rules. **You must not break the rules.**

**Rules**

There are 3 rules:

- You get more points for yellow than blue. Don’t forget then, **yellow gives you more points**, you should do more yellow things.
- You get extra bonus points for **each pot you fill up**. So it’s a good idea to fill things up.
- Only one bead in your hand at a time. So, only **one**, not two.

I’ll say those 3 rules again – you say them right after me. Pay attention – I want you to remember them:

- Yellow gets more points than blue.
- Filling up gets extra bonus points.
- Only one bead in your hand.

**Free recall rule learning**

Now - can you tell me the 3 rules?
Cued rule learning

*Every child is asked these questions – regardless of perfect spontaneous recall of rules*

What is special about yellow things? (More points than blue)

How long do you have to play the game? (1 minute until the sand runs out)

Do you think you could finish the game before the sand runs out? (No)

When does the game stop? (After 1 minute when the sand time runs out)

Can you have more than one bead in your hand at a time? (No)

Why should you go as quickly as you can? (To get lots of points before time runs out fill things up)

Why should you try to fill up pots? (To get extra bonus points)

Planning

We'll play soon – but first I want you to tell me how are you going to play? What are you going to do? (Record verbatim)

*Tell me as well as show me*

*Note where a plan is prompted (P)*

Well done – now we are going to play. Remember:

- Yellow gets more points than blue.
- Filling things up gets extra bonus points.
- Only one bead in your hand.
Performance

Are you ready to play the game?

Ready...steady...GO!

*(Turn over timer and start stopwatch)*

<table>
<thead>
<tr>
<th>Time started</th>
<th>Items placed/completed</th>
<th>Switch time</th>
<th>Rule breaks?</th>
<th>Time Checks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stop!  *Recount and Rule Memory*
Recount

Can you tell me what you did in the game? How did you play the game? Why? (Record verbatim)

*Tell me as well as show me

Rule Memory - free recall

Can you remember the 3 rules? What were they?

- Yellow get more points than blue.
- Filling up gets extra bonus points
- One bead at a time.
Rule memory - cued recall

What was special about yellow things? (More points than blue)

How long did you have to play the game? (1 minute until the sand time runs out)

Do you think you could have finished the game before the sand runs out? (No)

When did the game stop? (After 1 minute when the sand time runs out)

Could you have more than one bead in your hand? (No)

Why did you go as fast as you could? (To get lots of points before time runs out fill things up)

Why should you have tried to fill up a pot? (To get extra bonus points)

Count

<table>
<thead>
<tr>
<th>Task</th>
<th>Yellow</th>
<th>Blue</th>
<th>Full Yellow</th>
<th>Full Blue</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Yellow items (Full/ Not full)</th>
<th>Blue items (Full/ Not full)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow tall</td>
<td>Blue tall</td>
</tr>
<tr>
<td>Yellow square</td>
<td>Blue square</td>
</tr>
<tr>
<td>Yellow rectangle</td>
<td>Blue rectangle</td>
</tr>
<tr>
<td>Yellow large</td>
<td>Blue large</td>
</tr>
</tbody>
</table>
# Battersea Task – Single Task Score Sheet – Beads

<table>
<thead>
<tr>
<th>Name:</th>
<th>School:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date tested:</td>
<td>DOB:</td>
</tr>
<tr>
<td>Video Code:</td>
<td>Age:</td>
</tr>
</tbody>
</table>

## Rule Learning Score

<table>
<thead>
<tr>
<th>Free recall Rule Learning</th>
<th>Yellow things get more points than blue (1/2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Filling up gets extra bonus points (1)</td>
</tr>
<tr>
<td></td>
<td>One thing in your hand (1)</td>
</tr>
<tr>
<td>Spontaneous rule learning total</td>
<td>Score out of 4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cued Recall Rule Learning</th>
<th>What is special about yellow things? (1/2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>How long do you have to try? (1)</td>
</tr>
<tr>
<td></td>
<td>Finish before sand runs out? (1)</td>
</tr>
<tr>
<td></td>
<td>When does the game stop? (1)</td>
</tr>
<tr>
<td></td>
<td>More than one thing in your hand? (1)</td>
</tr>
<tr>
<td></td>
<td>Why go as fast as you can? (1)</td>
</tr>
<tr>
<td></td>
<td>Why try to fill up? (1)</td>
</tr>
<tr>
<td>Cued recall total</td>
<td>Score out of 8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rule learning score</th>
<th>Free + cued recall scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Score out of 12</td>
</tr>
</tbody>
</table>

## Planning Score

<table>
<thead>
<tr>
<th>Plan task score</th>
<th>Beads (1/2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total plan yellow score</td>
<td>Yellow beads (1)</td>
</tr>
<tr>
<td>Total plan fill score</td>
<td>Fill pots (1)</td>
</tr>
<tr>
<td>Planning summed score</td>
<td>Sum all the planning scores</td>
</tr>
<tr>
<td></td>
<td>Score out of 4</td>
</tr>
</tbody>
</table>

## Plan Following Score

<table>
<thead>
<tr>
<th>Following plan task score</th>
<th>Plan task score (as above, out of 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beads not performed (-1)</td>
</tr>
<tr>
<td>Total following plan task score</td>
<td>Score range 0 to 2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Following plan yellow score</th>
<th>Plan Yellow Score (as above, out of 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subtract 1 point for yellow beads not prioritised</td>
</tr>
<tr>
<td>Total following plan yellow score</td>
<td>Score range 0 to 1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Following plan fill score</th>
<th>Plan fill score (as above, out of 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subtract 1 point for beads not full first</td>
</tr>
<tr>
<td>Total plan fill score</td>
<td>Score range 0 to 1</td>
</tr>
</tbody>
</table>
### Single Task Performance Score

<table>
<thead>
<tr>
<th>Performance Variable</th>
<th>Task</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task attempt score (1)</td>
<td>Beads (1)</td>
<td></td>
</tr>
<tr>
<td>Yellow item first (1 point for single yellow item played first)</td>
<td>Beads (1)</td>
<td></td>
</tr>
<tr>
<td>Small item first (2 points for smallest, 1 point for medium, 0 points for large)</td>
<td>Score range 0-2</td>
<td></td>
</tr>
<tr>
<td>Fill item first (1 point if the first item attempted is full before proceeding)</td>
<td>Beads (1)</td>
<td></td>
</tr>
<tr>
<td>Number of small yellow items complete (Bd: tall/sq/rect)</td>
<td>Beads (1-3)</td>
<td></td>
</tr>
<tr>
<td>Prioritise yellow? = Binomial formula Y&gt;B = award 1 point/ Y&lt;B = award 1 point if all small Y full</td>
<td>Beads (1)</td>
<td></td>
</tr>
<tr>
<td>Prioritise yellow score</td>
<td>Score out of 1</td>
<td></td>
</tr>
<tr>
<td>Total Strategic Performance Score</td>
<td>Score out of 6</td>
<td></td>
</tr>
<tr>
<td>Error score (score 1 negative point for item placed in the wrong container)</td>
<td>Beads (-1)</td>
<td></td>
</tr>
<tr>
<td>Error score</td>
<td>Score 0 to -1</td>
<td></td>
</tr>
<tr>
<td>Rule break score (score 1 negative point for breaking 1-in-your-hand-rule)</td>
<td>Beads (-1)</td>
<td></td>
</tr>
<tr>
<td>Rule break score</td>
<td>Score 0 to -1</td>
<td></td>
</tr>
<tr>
<td>Total Penalty Performance Score</td>
<td>Score 0 to -2</td>
<td></td>
</tr>
<tr>
<td>Single Task Performance Score (+ve + -ve)</td>
<td>Score 0 - 6</td>
<td></td>
</tr>
</tbody>
</table>

### Recount Score

<table>
<thead>
<tr>
<th>Task score</th>
<th>Beads (1/2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recount Score</td>
<td>Range 0 to 2</td>
</tr>
</tbody>
</table>

### Retrospective Memory Score

<table>
<thead>
<tr>
<th>Retrospective free recall score</th>
<th>Yellow things get more points than blue (1/2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filling up gets extra points (1)</td>
<td></td>
</tr>
<tr>
<td>One thing in your hand (1)</td>
<td></td>
</tr>
<tr>
<td>Retrospective free recall total</td>
<td>Score out of 4</td>
</tr>
<tr>
<td>Retrospective cued recall score</td>
<td>What is special about yellow things? (1/2)</td>
</tr>
<tr>
<td>How long do you have to try? (1)</td>
<td></td>
</tr>
<tr>
<td>Finish before sand runs out? (1)</td>
<td></td>
</tr>
<tr>
<td>When does the game stop? (1)</td>
<td></td>
</tr>
<tr>
<td>More than one thing in your hand? (1)</td>
<td></td>
</tr>
<tr>
<td>Why go as fast as you can? (1)</td>
<td></td>
</tr>
<tr>
<td>Why try to fill up? (1)</td>
<td></td>
</tr>
<tr>
<td>Retrospective cued recall total</td>
<td>Score out of 8</td>
</tr>
<tr>
<td>Rule memory summed score</td>
<td>Free recall total + cued recall total</td>
</tr>
<tr>
<td>Score out of 12</td>
<td></td>
</tr>
<tr>
<td>Additional scores</td>
<td>Frequency of rule breaks</td>
</tr>
<tr>
<td>Number of timer checks</td>
<td></td>
</tr>
</tbody>
</table>

### Additional Comments:
Appendix 5

Behaviour Rating Inventory of Executive Function

(BRIEF)
Appendix 5: Behaviour Rating Inventory of Executive Function

BRIEF - Behavior Rating Inventory of Executive Function

Authors: Gerard A Giola, Peter K Isquith, Steven C Guy & Lauren Kenworthy.

Publisher: PAR - Psychological Assessment Resources, Inc, FL, USA

An 86 item Parental Questionnaire. Answers are scored as occurring:
Never
Sometimes
Often

Answers subdivided into 8 sub-scales:

Inhibition (10 Q’s) (Inb)
- Acts wilder or sillier than others in groups (birthday party, recess)
- Interrupts others
- Gets out of seat at wrong times
- Gets more out of control than friends
- Blurts things out
- Acts too wild or “out of control”
- Has trouble putting brakes on his/her actions
- Gets in trouble if not supervised by an adult
- Becomes too silly
- Talks at the wrong time

Shift (8 Q’s) (S)
- Resists or has trouble accepting a different way to solve a problem with schoolwork, friends, chores etc.
- Becomes upset with new situations
- Tries the same approach to a problem over and over even when it does not work
- Acts upset by a change of plans
- Is disturbed by a change of teacher or class
- Resists change of routine, foods, places etc.
- Has trouble getting used to new situations (classes, groups, friends)
- Thinks too much about the same topic

Emotional Control (10 Q’s) (EC)
- Overreacts to small problems
- Has explosive angry outbursts
- Becomes tearful easily
- Has outbursts for little reason
- Mood changes frequently
- Reacts more strongly to situations than other children
- Mood is easily influenced by the situation
- Angry or tearful outbursts are intense but end suddenly
- Small events trigger big reactions
- Becomes upset too easily
Appendix 5: Behaviour Rating Inventory of Executive Function

Initiate (8 Q's) (I)
- Is not a self-starter
- Needs to be told to begin a task even when willing
- Has trouble coming up with ideas for what to do in play or free time
- Has trouble getting started on homework or chores
- Has trouble organising activities with friends
- Does not take initiative
- Complains there is nothing to do
- Lies around the house a lot ("couch potato")

Working Memory (10 Q's) (WM)
- When given 3 things to do, remembers only the first or last
- Has a short attention span
- Has trouble concentrating on chores, schoolwork etc.
- Is easily distracted by noise, activity, sights etc.
- Has trouble with chores or tasks that have more than one step
- Needs help from an adult to stay on task
- Forgets what he/she was doing
- When sent to get something, forgets what he/she was supposed to get
- Has trouble finishing tasks (chores, homework)
- Has trouble remembering things, even for a few minutes

Plan/Organise (12 Q's) (P/O)
- Does not bring home homework, assignment sheets, materials, etc.
- Has good ideas but cannot get them on paper
- Does not connect doing tonight's homework with grades
- Forgets to hand in homework, even when completed
- Gets caught up in details and misses the big picture
- Has good ideas but does not get the job done (lacks follow-through)
- Becomes overwhelmed by large assignments
- Underestimates time needed to finish tasks
- Starts assignments or chores at the last minute
- Does not plan ahead for school assignments
- Written work is poorly organised
- Has trouble carrying out actions needed to reach goals (saving money for special item, studying to get a good grade)

Organisation of Materials (6 Q's) (OM)
- Leaves playroom in a mess
- Keeps room messy
- Cannot find things in room or school desk
- Leaves a trail of belongings wherever he/she goes
- Leaves messes that others have to clean up
- Has a messy closet
Appendix 5: Behaviour Rating Inventory of Executive Function

Monitor (8 Q’s) (M)
- Does not check work for mistakes
- Makes careless errors
- Has poor handwriting
- Is unaware of how his/her behaviour affects others
- Does not notice when his/her behaviour causes negative reactions
- Has poor understanding of own strengths and weaknesses
- Work is sloppy
- Does not realise that certain actions bother others

Non-scored Questions (13 Q’s) (NS)
Note the last 13 questions are not scored directly. Presumably in part to prevent question answering response patterns/fatigue. Also these questions are also used to calculate possible parent negativity (see below).
- Has trouble waiting for turn
- Loses lunch box, lunch money, permission slips, homework etc.
- Cannot find clothes, glasses, shoes, toys, books, pencils etc.
- Tests poorly even when knows correct answers
- Does not finish long-term projects
- Has to be closely supervised
- Does not think before doing
- Has trouble moving from one activity to another
- Is fidgety
- Is impulsive
- Cannot stay on the same topic when talking
- Gets stuck on one topic or activity
- Says the same things over and over
- Has trouble getting through morning routine in getting ready for school

Index Scores

**Behaviour Regulation Index**: inhibition, shift and emotional control sub-scales are summed.

**Metacognition Index**: initiate, working memory, plan/organise, organisation of materials and monitor are summed.

**Global Executive Composite**: all scores

Other Scales
Also included are two other scales:

**Negativity Rating Scale**
9 items are classified as negativity items, if a score of 3 (often) is awarded on a negativity item, this is recorded. The total number of negativity items are recorded and classified as:
- ≤ 4 = acceptable
- 5-6 = elevated
- ≥ 7 = highly elevated

**Inconsistency Scale**
20 items are selected for consistency rating. These are divided into 10 pairs. The scores for each pair are selected and compared to one another. The difference is scored (lesser score subtracted from greater score) and the result for each pair is summed from a possible total of 20:
- ≤ 6 = acceptable
- 7-8 = questionable
- ≥ 9 = inconsistent