Temporal experience after severe brain injury

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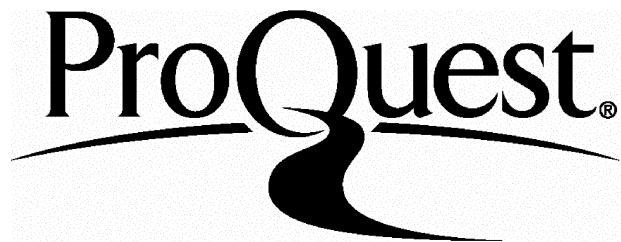
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Abstract

Relatively little is known about the cognitive nature of temporal experience or 'psychological time' after brain damage, despite the importance of temporal regulation of action for normal social adaptive behaviour. Practising clinicians are confronted with a wide range of problems associated with disturbances of the subjective appreciation of time, all of which are central to the complex manner in which action is organised in temporal contexts. Yet in neuropsychological terms these different aspects of psychological time pertain to difference cognitive abilities. This thesis constitutes a preliminary exploration of the nature of psychological time and how this may break down after severe brain injury in terms of the underlying cognitive processes. Experimental group studies are reported, supported by detailed single-case investigations, which suggest revisions to current theoretical accounts of time experience. In general, the empirical data support the notion of an internal timing system susceptible to attentional mediation, while translation of temporal awareness into a form useful for goal-directed behaviour entails the additional operation of executive skills. Episodic and semantic memory processes also contribute to temporal regulation of action in terms of sustaining a complex network of temporal representations based upon past events, knowledge about time and linguistic and numerical aspects which are necessary for communication about time. This in turn underlies the development of shared notions of time essential to social adaptation. It is argued that the psychological experience of time involves multiple temporal perspectives and that no single theory can provide an adequate conceptual framework for clinicians. Disturbances in temporal awareness can involve either dysfunction of a neural timing system sensitive to the operation of attention, or to impairments in a wide range of other general purpose information processing systems which contribute to the broader notion of psychological time.

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Chapter 1.

The concept of Psychological Time

This research was motivated by two principal concerns, to explore the everyday experience of time and to understand how temporal awareness is impaired following severe brain injury. Time experience would seem to require a range of cognitive skills and should therefore be amenable to neuropsychological analysis at the level of cognitive systems and their neural organisation. However, temporal awareness is more than an evolutionary adaptation; History traces scientific and technological developments in conceptualising, measuring and using time. Thus, in a clinical capacity, a broader perspective is often necessary incorporating cognitive deficits within wider intra-personal and inter-personal contexts. The development of complex social systems and organisations requires a common ability to appreciate time and temporal relations between events. Awareness of time therefore fulfils an important social function. It is because this social aspect of what is essentially a cognitive process is so crucial to effective functioning that disturbances of temporal awareness can be so disabling. Nowhere is this more apparent that when working with very severely brain-injured people, for whom effective rehabilitation requires an integration of cognitive models of mental processes with frameworks for understanding the associated social and functional handicaps. This thesis presents an examination of some of the key issues that need to be addressed in working towards a clinical neuropsychology of temporal perspective.

1.1 Introduction to Psychological Time

In this first chapter the historical and philosophical grounds for the psychological study of time will be briefly reviewed in so far as they provide a rationale for the subsequent empirical and theoretical chapters. Such is the prevailing domination of time in current political, economic and social contexts that psychological time cannot be considered simply in terms of intra-personal factors. The present chapter will trace briefly the key stages in the origins of the modern-day economic model of time and the development of

time measurement. The social function of time will then be discussed and finally, a proposal presented for the relevance of temporal perspectives for action. Thus chapter 1 will provide the background for a working model of psychological time which is adopted throughout the thesis.

1.1 (i) The origins of Psychological time

The origins of the psychological study of time can be traced to Antiquity. The Greek Idealist school, originating from Parmenides (early 5th Century BC) declared that the physical world was timeless and unchanging, in contrast to the surface world of appearance (Cornford,1950). This notion that time and change are unreal is exploited in the well-known paradoxes of Zeno of Elea (see Owen,1957) and its intellectual residue survived until recently (eg. Meyerson,1930). In contrast to the doctrine of the unreality of time, Plato (427-347 BC) conceptualised time as very much an intrinsic part of the natural world, caused by celestial revolutions. Subsequently Aristotle (384-322 BC) in his natural philosophy emphasised the importance of time measurement (Capek,1976) and the primacy of the temporal instant (Owen,1979). In Aristotle's *Physics, Book IV* there is an early reference to time having a psychological dimension: "when the state of our minds does not change at all, or when we have not noticed its changing, we do not realise that time has elapsed," (cited in Sorabji,1979). In a similar vein, the Roman poet Lucretius (99-55 BC) later wrote: "time by itself, does not exist .... It must not be claimed that anyone can sense time itself apart from the movement of things or their restful immobility," (*De Rerum Natura*). However, the most significant early contribution to the psychological study of time came later and was made by St Augustine (354-430) who famously asked: "What then, is time?...if no-one asks me I know; if I wish to explain to him who asks, I know not," (*Confessions*). Augustine conceived of time as the basis for memory, perception, anticipation and expectation (Jaques,1982) but, influenced by Aristotle, he also advocated the supremacy of the present, thus emphasising the moment or instant of time rather than duration as the foundation for temporal awareness.

1.1 (ii) Psychological time versus physical time

A great deal of the philosophy of time is concerned with the status of what is known technically as 'temporal becoming' or the flow of time. Williams (1951) described this familiar experience: "time flows or flies or marches, years roll, hours pass...we speak as if the perceiving mind were stationary while time flows like a river, with the flotsam of events upon it." Although some theorists have argued that time really does flow in this way (Gale,1968; Zwart,1976; Schlesinger,1983), an equally vehement and distinguished group of scholars have argued that the flow of time is illusory (Russell,1915; McTaggart,1927; Smart,1955, Grunebaum,1963; 1964; 1968; 1971; Shorter,1984). Once acknowledged however, this philosophical debate can be disregarded because the main dispute concerns the nature of time itself rather than the nature of time experience. Fundamental to discussion of the nature of psychological time is the relation between time and change (Whitrow,1987; Mellor,1981;1993). Since the Ephesian Heraclitus (c.500 BC) proposed that it was impossible to step into the same river twice, these concepts have been inextricably linked.

The Empiricist philosophers proposed a reductionist[1] empirical concept of time, arguing that time awareness was derived from the succession of external events impinging on the senses. Thus Locke (1632-1704) formulated a psychological explanation for the sense of time racing by: "one who fixes his thoughts very internally on one thing so as to take but little idea of the succession of ideas that passes in his mind...thinks that time is shorter than it is." This raises some key issues about the role of attention and time experience which are explored in section 2 (chapters 4-7). For the present, it is worth noting that the empiricist approach may be seen as setting some necessary conditions for time experience but not providing a sufficient basis for temporal awareness.

An alternative notion of psychological time is provided by the Idealist or constructionist school which can be traced to Liebniz (1642-1727). Like the Empiricists, Liebniz and

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[1] Reductionism in this sense contends that all assertions about time can be construed as assertions about the temporal relations between things in time (Newton-Smith,1980).

later Kant (1724-1804) believed that awareness of time was grounded in sensory experience but both recognised that this was inadequate to account for the concept of time. They looked for explanations in terms of the way the mind constructs time from experience, predating the cognitive approach now in the ascendancy. In fact Liebniz was really concerned with physical time which he believed was derived from events (Morris,1934). Yet the considerable emphasis he laid on the subjective nature of temporal experience is still relevant for a more circumscribed account of psychological time.

Interestingly, the essential feature of time for Liebniz, as it had been for Descartes (1596-1650) and the Empiricists, was the idea of succession; the present (pre-eminent in Classical and Mediaeval thinking) was relegated to little importance. Here can be seen the origins of a move away from the instant of time as the only reality to a view that a stream of successive instants is a more valid notion . However, this concept of psychological time, based only on a succession of present moments, does not seem adequate to account for the richness of temporal experience and has itself been criticised for example by (Kummel,1966) for denying the reality of past and future. Certainly it is fundamental to subjective experience that time has continuity, and that individuals are extended in time. For philosophical insights into this aspect of time the Twentieth Century phenomenological school provides interesting subject matter. In particular, the views of Heidegger and Bergson are relevant, but will only be given cursory mention as an illustration of the diverse metaphysical influences on the concept of psychological time.

The importance of human temporality formed the basis of Heidegger's (1962) complex philosophical treatise *Being and Time* which was heavily influenced by the ideas of his compatriot Kant (Sherover,1971). The central role of time was also a key aspect of Bergson's (1910;1911) metaphysics. When considering breakdowns of time awareness after psychiatric or neurological illness, then Bergson's concept of *duree* as the temporal perspective within which action occurs, and Heidegger's emphasis on the role of

temporal continuity in sustaining personal identity are both important perspectives in addition to the more cognitively-attractive philosophy of Liebniz.

Summary

In summary, the Western origins of the psychological study of time can be traced to Antiquity where conscious awareness of change was identified with an appreciation of the passing of time. Aristotle and later St. Augustine may be credited with the impetus for psychological concepts of time, although contemporary thought owes much to Liebniz in asserting that events are primary, and that time is derived from their apprehension. Phenomenological explorations have stressed the continuity of time as a foundation for action and personal development.

1.2 The Social Construction of Time

The time basis within which many social processes operate is largely assumed in research, as time is frequently an independent variable in both Psychology (McGrath & Kelly,1992) and Sociology (Bergmann,1992). Recently, Nowotny (1992) has argued for social theory to recognise the importance that individuals place on being in control of their time, structuring and employing it towards meaningful goals; hence the dismay over "lost" time associated with the replacement of the Julian calendar (1752) and the introduction of British Summer time in 1916 (see also chapter 11). This section will review the role of the clock as the medium of social representations of time, and briefly discuss the development of temporal perspective. It will be argued that effective functioning in Society requires the ability to sustain multiple temporal perspectives in organising behaviour.

1.2 (i) The concept of a clock

The ability to regulate behaviour within temporal constraints depends largely on understanding conventional representations of time. Primitive clocks existed in Egypt and China 4000-3500 years ago. The Latin word *clok* and the English version *clocke*

appear in the late Fourteenth Century (Burton,1979), being corrupted from the name given to a type of weight-driven mechanical device (*horologia*) which struck a bell (*clocca*). The earliest contemporary drawing of a Mediaeval water-clock is in an illuminated bible *circa*1285, while an Italian fresco of 1337-39 shows the earliest known illustration of a sandglass. Ball-shaped watches existed from about 1500 but the modern science of time-keeping began with the Dutch astronomer Huygens, inventor of both the pendulum clock and the spring balance for pocket watches. Nevertheless, mechanical clocks did not replace the most sophisticated shadow clocks (helio-chronometers) as primary time-pieces until the Nineteenth Century. The clock is now such a predominant social icon that inability to interpret and use this form of temporal representation may be severely disabling. The cognitive processes which underlie this skill are examined in chapter 11 where it is argued that the ability to tell the time is not just a cognitive acquisition but serves an important psychological and social function integrating other aspects of time experience.

1.2 (ii) The development of Temporal perspective

A number of authors from different persuasions have highlighted importance of temporal perspective in guiding human action. For example, the most celebrated psychologist to study time Paul Fraisse (1963) referred to "temporal horizons" as representing the extent to which present actions are influenced by considerations of past events or future objectives. Social psychologists Gorman and Wessman (1977) referred to temporal perspective as "the degree to which a person, group or society conceptualises events removed from the present situation" (p.228). This is not a novel or even uniquely human attribute although *Homo sapiens* has been able to develop a sense of temporal perspective far beyond the complexity of other animals. Indeed, throughout history, with the design of increasingly sophisticated instruments to measure time, civilisations appear to have become increasingly time-oriented (Adam,1992; Neustadter,1992). Evidence from paleolithic cave paintings and burial sites seems to suggest that early Man operated in a temporal perspective although probably rather different from present-day notions of

time. Even highly organised ancient civilisations such as the Egyptians and Mesopotamians measured only the present and were extremely vague about their own past. The concept of history as we recognise it was a Western development in part attributable to the Greek "fathers of history," Thurydicles and Herodotus in the Fifth Century BC. Still, the Egyptions could be credited with the most relevant early contribution to the latter-day social construction of time by virtue of their division of the year into twelve months and 365 days. Much later the Northumbrian Benedictine monk Bede (673-735), who wrote the first English history, also made significant contributions to chronology in his *De temporum ratione* (On the Reckoning of Time) and introduced the A.D. dating system to England.

In the Middle Ages clocks with only one hand and quarter-hour divisions established concepts of time as an economic resource, for the mercantile classes at least. The introduction of mechanical clocks from the Fourteenth Century promoted the standardisation of the sixty-minute hour as the unit of labour, while the cyclical regularity of the seven-day week may be attributed to later Puritan influences (Whitrow,1988). However, the modern social dimension to time really evolved during the Eighteenth and Nineteenth centuries which saw great changes in time measurement and its role in Society. The invention of the marine chronometer (1742), the adoption of the Gregorian calendar in 1752, the scientific community's rejection of Biblical time scales, the adoption of uniform railway timetables, developments in thermodynamics and the discovery of radioactivity which indicated the now familiar unidirectional nature of time - these events dictated a profound change in the role of time in people's lives (Toulmin & Goodfield,1967). Behaviour at an individual and group level was increasingly regulated according to the temporal standards of the age. Effective contribution to Society therefore was to depend for everafter, not just on possession of requisite skills, but an ability to function within a common temporal horizon or perspective.

Presently the predominant model is the "temponomic" concept (McGrath & Kelly,1986), designating time as a scarce resource and valued medium of exchange. Time is viewed

as something we can 'buy' or lose or give up, according to demand. This has profound implications for individuals unable to function within such a pre-eminent socio-political context, particularly in Western society where, in contrast to some cultures, popular time is linear, universal and consistent, and people are expected to share common temporal experiences.

1.2 (iii) The nature of temporal perspective

The richness of temporal vocabulary and metaphors for time reflects both the conceptual complexity of time in society (Jackson & Michon,1992) and the ontological status of the individual (Orme,1969). Indeed, many of these ideas develop during early childhood (Friedman,1982) such as the clock-durations of a minute and an hour, the solar-lunar rhythm of a day and more abstract notions of weeks and months. Longer intervals and perceptually vague durations (such as "in a while") are learned later (Westman,1987).

Temporal perspectives or time scales may be organisational and cultural as well as personal (Needham,1966; Nakamura,1966; Ostor,1993). The extensive use of time-diaries to record behavioural patterns over several years demonstrates political, cohort and class differences in the way people structure their daily life (Robinson,1988). Furthermore, judgements of duration are influenced by social cues (Ahmadi,1984). Levine & Wolff (1985) demonstrated cultural differences in everyday activities such as walking pace, acceptable clock accuracy and waiting time for a garage attendant, which they interpreted as reflecting the greater time-pressured societies of England, the USA and especially Japan, compared with Italy and Indonesia. Moreover, within Western Society predictable differences emerge, middle-class children tending to be more future-oriented and less present-focused than their working-class peers (Gonzales & Zimbardo,1985; Bergmann,1992).

The social and psychological dimension to time representations is encapsulated in Friedman's (1990) notion of 'mental models' of temporal perspective. Although his

terms are inadequately specified, they entail the important suggestion that there may be both conventional (public) time-frames and personal frames of temporal reference (eg. my birthdate, my holidays, one hour before my driving test). Certainly, autobiographical experience appears to play a part in formulating semantic associations (Snowden et al.,1994) and there is already evidence that private events may be reflected in the representation of numbers (Cohen et al.,1994). In chapter 11 the possibility is raised that temporal representations are also likely to have idiosyncratic associations in this manner.

1.2 (iv) Multiple temporal perspectives

It is implicit throughout the thesis that regulation of behaviour requires some degree of temporal perspective. Apperception of a train of successive events cannot account for the subjective sense of temporal continuity; an endless series of novel events could not permit predictions about behaviour. Of necessity, contemporary Society functions with regard to a variety of time-pressures and multiple temporal perspectives (McGrath & Kelly,1986). These time-frames appear to form crucial mediators of subsequent action, for example, in terms of setting limits on the duration of activities, constraining plans and objectives, and selecting and attending to relevant information.

Inevitably time-scales come into conflict: a year is actually about 365.2422 days long, a lunar month is approximately 29.5306 days; thus adjustments have to be made to the scientific division of what may be considered "social time." Indeed, McGrath and Kelly (1986) and McGrath (1988) have argued that the time of our adult day-to-day experience does not map onto a modified Newtonian model, based on linear succession, but instead fits a spiral relational notion based on duration which they term a transactional view: "Human life involves oscillations, with periodicities all the way from seconds and microseconds to major stages of a life-span...[involving] patterns that are cyclical, epochal and relational," (McGrath,1988 p.257). Unfortunately, research on human behaviour within these different time-scales has been theoretically weak, and largely conducted independently.

It is clear that there is no single universal time-frame within which behaviour is regulated (Rabbitt,1996), the social function of time necessitates integration of multiple temporal domains. For example, Schank and Abelson (1995) argued that memory fulfils its role in social communication by narrative means, in terms of the construction and re-interpretation of "stories" based on past experience, which form a "remembered self." In this sense stories are a dynamic evolving process, in contrast to the fixed behavioural packages which constitute "scripts" (Schank & Abelson,1977). Semantic memory then becomes a repository of facts which serve as indexes for stories. From this perspective, the experience of time and development of temporal concepts is part of an unfolding, socially-constructed process, impairment of which necessarily carries social implications (see chapters 4 and 10). In cognitive terms disability occurs when behaviour cannot be regulated according to some standard (eg. calendar or clock time), but a narrative perspective also demonstrates how social communication breaks down as individuals cannot utilise the interpretative contexts provided by shared social cognition.

The consequences of temporal disorientation or unawareness of the passage of time carry significant social handicaps as well as individual impact. It follows that a comprehensive understanding of the psychological sequelae of impairments in time estimation arising through neurological illness or psychiatric disorder requires consideration of the associated functional and social consequences. Hence any description of the clinical relevance of temporal awareness requires a broad sweep of analysis, involving multiple concepts of time. A crucial, though often unappreciated, aspect of neuropsychological rehabilitation involves promoting the ability to function within different time-scales or temporal perspectives. However, no single theoretical perspective or experimental model will suffice for the clinician wishing to understand and improve disturbances of temporal experience after brain injury. Until recently there has been little systematic effort to discuss the complex temporal dimensions by which individual and social behaviour is guided, and no attempt to consider clinical disturbances of time awareness in this context (these are issues addressed in chapters 11 to 13). It is appropriate at this stage, therefore,

to consider the development of psychological models of time. An appreciation of current thinking about the subjective experience of time provides the necessary ground for detailed investigation of individual clinical disturbances of time awareness and the functional implications that can result in a social context.

Summary

Time is fundamentally an aspect of phenomena (Whitrow,1972) and the model of subjective time in the present research recognises events as primary, following Liebniz. Events permit awareness of time by virtue of causing changes in biological systems equipped not only to respond to stimuli but with a capacity to recognise that change has occurred. These issues have been much elaborated in recent studies of the cognitive processes and social influences underlying temporal experience. Several key issues have been identified: the social aspects of psychological time entail familiarity with clocks and their meaning, adoption of a common temporal horizon and the ability to sustain multiple temporal perspectives guiding action. The cognitive aspects of psychological time are discussed in some depth in chapter 2.

Chapter 2

Models of Psychological Time

Since the inception of experimental psychological investigation there have been many attempts to encompass the complexity of human temporal experience within a single conceptual framework, emphasising both psychophysical relations with external events (Titchener,1905) and experiential aspects (Rubin,1936). Early textbooks of experimental psychology included chapters devoted to time perception (Titchener,1905; Myers,1911). Time later appears only as an independent variable in Woodworth & Schlosberg's (1954) experimental textbook though a chapter on time perception is included in Stevens' (1951) classic, only to be omitted in the second edition (Atkinson et al.,1988) despite an expansion of chapters on cognitive processes from one to seven. Underwood's (1966) text on experimental psychology includes a chapter on time perception but there is scant mention of time in Neisser's (1967) seminal cognitive work or in later texts (Kantowitz,1974, Norman & Rumelhart,1975). In spite of centuries of recognition of time as essential to phenomenal experience and action, it is perhaps a reflection of the inherent elusiveness of the concept, as much as the current trend, that time is no longer a mainstream topic in cognitive psychology texts (eg. Eysenck & Keane,1990). As a result much of the recent research on time estimation shows little integration with contemporary cognitive psychology.

Although time-related studies of individual and group processes are rarely integrated in conceptual terms (see chapter 1), an important premise underlying the research presented in the thesis is that the social consequences of time awareness are derived from the psychological aspects of temporal experience. Thus one cannot truly understand the functional deficits arising from anomalous time experience without appreciating associated cognitive distortions. Following a brief summary of the role of the subjective present in maintaining continuity of awareness, this chapter will review the key methodological and conceptual frameworks for studying estimated duration. Two broad

classes of model will be identified, distinguishable in terms of whether they postulate an intrinsic timer mechanism (internal clock models) or they assume that psychological time is constructed from general information processing systems. This will lead to a review of cognitive components of psychological time which will provide the conceptual background and organisational framework for the rest of the thesis.

2.1 Time experience in the present

It is important to distinguish temporal thresholds in perception, the notion of a discrete quantum of subjective duration, otherwise known as the "perceptual moment" (eg. Stroud,1955;White,1963), from the notion of a psychological present. Detailed discussion of perceptual threshold studies is beyond the scope of the present review but the results are well summarised in Fraisse (1984), Whitrow (1987) and Patterson (1990).

Philosophical objections to the existence of the present notwithstanding (Bradley,1964; Mellor,1993), there is a rich tradition traceable to St Augstine of regarding the present as the only true basis for time and action. In contrast to the prevailing post-Newtonian view of the 'objective' present as an imperceptible interval between the future and the past, James (1890) argued that the psychological present derived from an overlapping of conscious moments caused by the fading of latent nervous activity. His functionalist approach validated the experience of temporal passage and preserved the continuity of consciousness which was threatened by the Empiricist philosophers (and later by structuralists like Titchener) in their search for elemental properties of phenomenal experience (Eisendrath,1971).

Although James entertained several contradictory notions about consciousness (Strange,1978), Natsoulas (1993) has argued that his concept of a specious present is better considered as a compartmentalised train (rather than a stream) with blocks of psychological time within which successive instances occurred, rather like Allport's (1968) "travelling moment." In a similar vein Boring (1933/63) acknowledged: "in terms of objective time the present is a mere point...without duration. However, introspection

is against this view. The present is quite real, it is immediately given as a 'going-on'...an actual conscious present...that can briefly preserve mental events from instantaneous obliteration in the past...." (p.134).

Experiments showing that changes in the latter stages of a process can influence the estimated total duration of an activity (Michon,1978; Boltz,1985) suggests also that the contents of the immediate present are available for re-structuring under higher-order interpretative influences (see section 2.4). Block (1979) is typical of many cognitive theorists in regarding the transitory psychological present as being based on these dynamic aspects of the information processing system. However, the subject is largely neglected in neuropsychology, given the current fashion for compartmentalising the building blocks for specific tasks at the expense of fragmenting the temporal continuity of cognition.

2.2 Methodological considerations in time estimation

A fundamental consideration in evaluating cognitive time estimation studies is the conditions under which the estimation was made. There are two principal methodological issues. Firstly, whether time is monitored during the course of an activity or estimated only after task completion; and secondly how the estimations were produced. These will be discussed briefly in turn.

2.2 (i) Prospective and retrospective time estimation

As indicated above, there are two generally accepted methods or paradigms which allow for subjects to provide time estimations. If subjects are only informed after the to-be-timed task has been completed that they are to estimate its duration, then this entails a *retrospective* temporal judgement sensitive to remembered time. In contrast, if subjects are forewarned before beginning the task of the need to estimate its duration upon completion, then the subsequent time estimation is presumed to reflect experienced rather than remembered time (Hicks,1992). Such a method is called a *prospective* time

estimation and is generally thought to be sensitive to the degree to which a person was able to attend to the passage of time during task execution - a kind of dual task in itself. Typically, this is considered a kind of trade-off, with greater task complexity recruiting more attention to task and less to time, thus resulting in prospective underestimations. Theoretically there should be an inverse relation between retrospective and prospective time estimations, as more demanding tasks yield prospective underestimates of time but provide more material in memory on which to base retrospective time estimates. Conversely, tasks which require little information processing capacity, such as waiting for an event to occur, tend to be overestimated prospectively but underestimated in retrospect as there are few high priority events to be remembered which could serve as cues to time (Zakay,1993a). Despite their intuitive appeal, these relationships hold only very broadly and are subject to modification by a number of extraneous variables. For example, if production of a prospective time estimation is delayed after task completion, this has the effect of lengthening estimated duration (Martinez,1994). Presumably this occurs because the delayed judgement is based more on memory and thus the foreknoweldge of having to attend to time which characterises the prospective paradigm is lost.

2.2 (ii) Methods of time estimation

Duration judgements can be made in relation to another interval (which of the two is shorter?) or in terms of some standard such as clock time (how long did it last?). The most relevant studies for the present review concern the latter so-called absolute judgements of duration, and these are described below.

There are in fact a bewildering variety of means of assessing time perception and experience depending on the nature of the stimuli and the time intervals involved (Nichelli,1996). Nevertheless Bindra and Waksberg (1956) described three commonly employed time estimation strategies from which most later methods were evolved (see also Zakay,1990). The most commonly encountered procedure, and that used throughout the present thesis is the *verbal estimation* method which simply requires subject to give

a verbal report of duration in terms of a conventional time scale such as seconds or minutes. Another method, less common but it is employed in chapter 10, is the *method of production* (or operative estimation) which requires the subject to delimit an interval of a required duration, for example by pressing a key. Sometimes subjects are requested to copy an interval with one of equal duration, a technique known as the *method of reproduction* but this is not used at all in thesis.

It is important to appreciate that the same subjective sense of duration gives rise to different experimental results depending on the strategy employed. For example, a person who experienced events in the world as passing very quickly (indicating a reduced rate of subjective time relative to clock time) would verbally underestimate the length of an interval (eg. declaring 15 minutes to be 5 minutes), but would produce an interval in excess of the required standard in a time production exercise (as subjectively their 15 minutes would be 45 minutes on the clock).

Furthermore, each method is associated with potential bias, indicating that the use of multiple time estimation methods is advisable. One of the most robust is the time-order error which affects the comparison of two intervals and can be partly be controlled for by alternating presentation of standard and target intervals. However, this presents additional complications for within-subject designs and the technique of interval comparison was not employed in the present research. Another common confounding factor is the central tendency bias, commonly observed when subjects are required to give repeated estimates of duration (Clausen,1950). Fortunately, this effect is most associated with operative estimation and reproduction methods and not the verbal estimation technique which is the principal means of time estimation used in the present research.

A final justification for using the verbal estimation method throughout the thesis as the principal means of assessing psychological time lies in the conceptual basis for the research. This has been elaborated in chapter 1 but essentially it was argued that the

facility to reflect on temporal experience serves an essentially functional purpose in enhancing behavioural self-regulation. This occurs through the medium of conventional representations of time, principally the clock and the calendar. Any deficiencies in the ability to regulate action within temporal parameters which could be attributed to poor temporal awareness are likely to be most clearly revealed by a method which directly assesses the relation between behaviour and clock time. Unlike the methods of reproduction and comparison, verbal estimation and also time production methods are employed in the present research because they are optimally suited to this strategy, necessitating translation into conventional time units, such as hours or minutes (Block, 1989).

One final methodological issue needs to be raised concerning the way that time estimation is described in the majority of empirical chapters in the thesis. Ideally, four aspects of a time estimation procedure should always be indicated. It has already been highlighted that different time estimation methods yield different kinds of information and are subject to different sources of error. Therefore firstly, it is important to know which method of time estimation was used. Secondly, in relation to the investigation of clinical abnormalities of psychological time the performance of an experimental group of subjects must be contrasted with that of another group similar with respect to all likely confounding influences except those which pertain to the experimental hypotheses. Thirdly, it is important to show a direction of bias in estimated time where it exists (ie. towards under or over estimation of interval duration). This is generally thought to be necessary in order to evaluate performance with regard to conceptual accounts of psychological time. Satisfying these three requirements has been done and will be discussed as appropriate in later chapters. However, in research on time experience it is also important to demonstrate how accurately subjects estimate time. Although the literature is replete with examples of under-estimation of time in one paradigm and of over-estimation in another, such research completely neglects the issue of accuracy. So universal is this neglect the issue that one can only presume that the omission is deliberate, perhaps because all the studies have been conducted on non-clinical samples,

whereby performance accuracy is not thought to be a credible dependent variable. This, of course, means that theoretical accounts are postulated in terms of their ability to predict relative bias (under or over estimation) rather than shortfalls in accuracy. In turn this means that potentially interesting data on accuracy have little impact to modify conceptual models which do not address the issue. This is a particularly vexing state of affairs when generalising theories from normative studies to clinical groups. At the risk of giving away the plot of later chapters, empirical investigation has shown that accuracy rather than direction of bias is the more useful and sensitive measure of time estimation anomalies associated with brain injury.

2.3   Timing with a timer: the internal clock

2.3 (i) The idea of an internal timer

First suggested by Descartes, biological clocks regulating arousal, temperature and hormonal secretions are now well-established (Francois,1928; Carrel,1931; Hoagland,1936,1966; Holubar,1969). Between 1927 and 1993 virtually all studies showed that experienced time increased as internal temperature increased (Wearden and Penton-Voak,1995), a finding consistent with the acceleration of a biological clock mechanism. It seems likely that biological clocks are subserved by structures sensitive to rhythmicity such as the suprachiasmatic nucleus (SCN) which receives a direct input from retinal photoreceptors and which innervates hypothalamic structures. Yet whether the SCN is anything more than a modulator for a variety of other internal clocks is unclear (Campbell,1989). Certainly, chemical pacemakers are inadequate to account for the diversity of human temporal experience (Michon,1971) though there may be other "hard-wired" mechanisms which permit a natural sense of time. Such biological processes may account for time distortions following acute illness or deprivation (Cohen,1967), but time estimation is thought to depend on body temperature only outside the normal thermal range (Hancock,1993). Similarly, physiological mechanisms such as sleep-wake cycles account for only very general estimates of duration (periods of several hours or days) and not for estimates of shorter periods (Campbell,1990). Conversely,

some studies have sought the neural representation of time in the temporal convergence of neural impulses which operate over much shorter time-scales (Artieda & Pastor,1996), but these are generally considered to be too brief and it is unclear how these processes would operate over periods of seconds or minutes (Miall,1996).

In contrast to the rather vague notion of a biological clock which was prevalent at the time, Mayo (1950) suggested that specific internal physiological processes may form a continuous uniform standard with which external events are correlated and their durations inferred. This is the principle underlying the concept of an internal clock which has dominated concepts of psychological time over several decades (Tayama,1987). Whereas biological clocks are periodic and thought to sustain circadian rhythms, the more usual notion of an internal clock implies regularity and some orderly relation to physical clock time (Orme,1969). Such a clock is generally thought to be triggered on signal and stops after running its course (Treisman,1963), although this basic concept has undergone considerable revision. Hence, the most established internal clock models are based on scalar timing theory, originally developed from animal work (Doty,1990; Roitblat & Young,1990) and now widely applied to human studies. The account which follows is largely derived from comparative work by Meck and colleagues (Meck,1984, 1986, 1988; Meck & Church,1987).

There are three independent stages to scalar timing. The clock itself is proposed to comprise a pacemaker generating regular pulses, and a switch or modality-specific switches (Rousseau & Rousseau,1996) that mediates transfer of pulses to an accumulator. In the *clock stage*, objective timing is translated into subjective time; this information is then stored in the *memory stage*. There are two memory components: current temporal information is held in a working memory buffer, while temporal information from past trials is stored in a reference memory. Temporally-regulated action occurs when the current clock reading is compared with previously sampled representations of temporal criteria in the *decision stage*. This is the basic functional

anatomy of an internal clock as the concept has been successfully employed in comparative studies of temporally-regulated behaviour.

2.3 (ii) The neurological basis of an internal clock

Because scalar timing theory, from which the functional anatomy of an internal clock has been formulated, is a psychological account questions as to its neural implementation have remained a somewhat secondary concern. The literature in support of internal clock mechanisms for time is largely based on studies of motor timing, which in turn have tended to emphasis procedural memory skills. However, the motor timing research principally concentrates on the cerebellum (Ivry & Keele,1987; Daum & Ackermann,1995), and reveals little explicit use of the internal clock concept, though some speculations have been made. For example, it is known that the inferior olivary nuclei (lying just below the pons) function as a cerebellar relay via climbing fibres (Burt,1993) and activate Purkinje cells during movement (Welsh et al.,1995). These structures appear to modify motor timing by signalling unexpected events, a function which may betray their role as a comparator in an internal clock mechanism (Miall,1992). Keele and Ivry (1991) have even suggested that a cerebellar timing mechanism may underlie classical conditioning, rhythmic movement, velocity and duration perception; certainly cerebellar lesions impair acquisition of conditioned responses (Bracha et al.,1997). However, it is doubtful whether a system designed to co-ordinate movements to accuracies within a few milliseconds could realistically be involved in psychologically more meaningful durations of seconds or minutes (Clarke et al.,1996).

Developments to internal clock mechanisms have involved increasingly complex efforts to identify their neural and cognitive organisation. Most accounts propose that timing is implemented in distributed neural circuits (Bressler,1996; Carr & Amagai,1996). Even for specific motor acts it is recognised that accurately timed movement involves many extra-cerebellar brain regions. It has been suggested that the basal ganglia may contribute to the monitoring of time through the organisation of movement for instance

(Pramstaller & Marsden,1996). This conflicts with the usual view based on the distinction between conscious or auto-noetic knowing (Tulving,1983) and non-conscious procedural control, whereby one might expect that poor subjective time estimation does not prohibit accurate motor timing. Instead, absence of motion may crucially disrupt or even eliminate subjective awareness of time. The remarkable facility with which "sleeping sickness" patients administered L-dopa could resume activities and pre-occupations after interruptions of several decades led Sacks (1973) to conclude that their post-encephalitic "standstills" were not accompanied by any sense of subjective duration. Another manifestation of dopaminergic insufficiency, Parkinson's disease, is also associated with poor temporal discrimination (Artieda et al.,1992; Pastor et al.,1992; Schnider et al.,1995). As well as basal ganglia structures, other brain regions implicated in timing include the anterior cingulate (Dum & Strick,1993), medial premotor (Chen et al.,1995), lateral premotor and supplementary motor areas (Passingham,1993), the hippocampus (Olton et al.,1987) septum (Mering,1989) and fornix (Meck et al.,1984a; Meck,1988), in addition to proprioceptive pathways (Larue et al.,1993).

In fact, there is reason to suspect that, so far as the timing of motor acts is concerned, this is predominantly undertaken by automatic control processes which leaves little room for the well-established influence of cognitive variables on subjective time awareness. Thus procedural learning of motor tasks is akin to a form of implicit or covert control as distinct from conscious learning. In Treisman's (1963) original internal clock model the same mechanisms involved in controlling the speed of action were also implicated in judging time, though he left unspecified the neural systems responsible. This implied that "if the single clock were damaged, a gross loss of co-ordination would occur, coupled with inability to appreciate the passage of time," (Treisman et al.,1992). Certainly clumsy children do show timing control problems (Williams et al.,1992) and Nicolson et al., (1995) have reported an association of motor skill deficits and poor time estimation in developmental dyslexia, but there is no evidence that this results from damage to a universal clock mechanism.

Specialised timing mechanisms are now thought to operate within relative time (Heuer & Schmidt,1988). That is, rates of clocks are adjusted as the tempo of performance requires it. Treisman et al., (1990;1992) suggested that this could be achieved by a calibration unit to modulate the pulse outputs of a temporal oscillator.[2] Alternatively, Miall (1996) proposed an 'integrator' model incorporating a mechanism for counting pulses from sensory systems corresponding to relevant events, in addition to a synchronous pulse from oscillator neurons for timing. Therefore, to the extent that these processes operate independently of higher-level cognitive control (ie. being mediated by attention or memory), the timing or speed of actions may have little bearing on the subjective appreciation of the passage of time. Alternatively, if actions or events are time-tagged or otherwise encoded automatically (Hasher & Zacks,1979) either cognitively or by an internal clock, then duration may be registered implicitly (see Paller et al.,1991).

2.3 (iii) Problems with internal clocks

As indicated above scalar timing is fundamentally a psychological - or behavioural - theory with little regard for the neuronal implementation of timing. Consequently the computational aspects may not be neurally-plausible (Ivry & Hazeltine,1992). In fact, as will be emphasised in chapter 3, there is no simple neural system to which an internal clock corresponds. Pharmacological experiments in animals have suggested that the proposed pulse rate may be modulated by dopaminergic systems (Meck,1986) possibly in fronto-striatal regions (Hicks,1992), and the memory aspects of the process appear to be susceptible to manipulation with cholinergic drugs (Meck & Church,1987). In humans, Pastor et al. (1992) showed that underestimation of time intervals by patients with Parkinson's disease could be countered with levodopa, was interpreted as evidence that dopamine agonists can "speed up" the internal timing mechanism. This is consistent

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[2] *Experimental studies of time perception and motor timing have indicated a running rate of the temporal pacemaker at just under 50 Hz. though more recent EEG investigations raise the suggestion of a 12.8 Hz. frequency modulation (Treisman et al.,1994).*

with animal work showing such an effect is predictable from a given neuroleptic's affinity for dopamine receptors (Meck,1986).

Another problem with internal clocks is that such models in their original form do not readily account for cognitive factors on timing such as information processing strategy or allocation of attention. For instance, they do not differentiate what it is that an animal is attending too. Comparative studies suggest that changes in reinforcement schedules can alter the pace of an internal clock (Bizo and White,1995), but initially some form of internal representation of temporal intervals appears necessary in order to appreciate reinforcement schedules (Meck et al.,1984b). In a comprehensive review, Roitblat and Young (1990) concluded that animal behaviour appears to be mediated by some form of abstract internal representation incorporating temporal dimensions of the world. Thus, modifications to internal clocks are becoming increasingly cognitive in nature. For example, Meck (1984) showed that the registration of putative pulses emitted by a pacemaker was influenced by attention.

Despite its longevity the internal clock model has remained somewhat impervious to advances in the cognitive sciences, its proponents have had relatively little to say about complex cognitive processes underlying human time experience, despite increasing evidence of the importance of cognitive mechanisms (Ivry & Hazeltine,1995). There would appear to be considerable potential, largely unrealised at the present time, for updating the internal clock model. For example, Fleury et al., (1994) showed that knowledge of results could modify movement pacing, possibly by establishing a consistent temporal reference. This suggests that the calibration process proposed by Treisman and colleagues is susceptible to cognitive manipulation. Allan (1992) has argued that the internal clock continues to offer a useful heuristic, and that cognitive theories should focus on integration with phenomena explained by an internal clock, rather than directed towards replacing such models. Yet modified internal clock models (eg. Thomas & Weaver,1975) which address the issue of nontemporal variables such as interval content and complexity on temporal experience succeed only by appeal to

cognitive constructs which raises the question of whether the notion of such a clock is superfluous. At this stage it is timely to consider the variety of alternative psychological theories invoked to explain time experience which differ from internal clock models by virtue of their emphasis on aspects of cognition.

2.4   Timing without a timer: psychological time as a cognitive process

Several authors have argued that the effects of cognitive manipulations on time experience undermine the notion of a single internal clock, whether directly related to subjective experience or acting as a pacemaker to other such clocks (Ornstein,1969; Block,1990a; Macar et al.,1992). Dissatisfaction with the more established internal clock models can be traced to the growth of cognitive psychology in the 1960s (Jackson,1990). This led to the proposal of alternative accounts based on information processing analogies, although the notion that psychological time is comprised of multiple aspects of cognition is traceable back to William James. In particular, James highlighted the crucial difference between the experienced duration of an activity and its remembered duration: "in general, a time filled with varied and interesting experiences seems short in passing, but long as we look back. On the other hand, a tract of time empty of experiences seems long in passing but in retrospect short" (cited in Block (1979), pg.191). In fact there are many different ways that the cognitive system is organised with respect to time. With regard to memory alone Block (1996) identified four aspects associated with time: procedural (for movement timing), semantic (for temporal concepts), episodic (which includes temporal details of events) and working memory (for maintaining current temporal context information). To this list of cognitive factors underlying subjective time one should also add both attentional processes and higher-level executive skills. The remainder of the present section will consider concepts of psychological time in terms of their emphasis on attention or memory processes. The contribution of semantic memory and executive skills to time experience is relatively neglected in the literature, but mention will be made of these domains too, where they appear to have relevance for specific models of time.

2.4 (i) Attention and Psychological Time

Both Locke and later James emphasised the importance of attention for time experience, and their intuitive theories have since received much empirical support. Specifically, two common distortions of psychological time are due to the mediating role of attention. Firstly, it is a common truism that absorbing or cognitively demanding tasks shorten the impression of passing time. Hence subjects in a card-sorting task gave shorter estimates of a 42 second interval when the sorting rules were made more complex (Hicks et al., 1976). This effect has been widely replicated with a variety of tasks (Bakan,1955; Smith,1969; Burnside,1971; McClain,1983; Brown,1985) and is also demonstrable in ergonomic studies (Liu & Wickens,1994). By contrast, individuals prone to boredom appear to perceive time as passing slowly (Watt,1991), consistent with similar experiences reported for clinically depressed individuals (Munzel et al.,1988) and controls in mood-induction studies (Hornik, 1992). Such results are difficult to account for solely in terms of the traditional internal clock which is reputed to "tick over" at a constant pace. Instead, cognitive theorists have invoked limited capacity attentional models, arguing that any activity becomes a dual-task exercise when attention to time is crucial. In such circumstances Norman (1969) predicted that serial attentional processes would inevitably result in loss of information for timings of events during unattended periods. Time experience can therefore be conceptualised as an outcome of competition for limited information processing resources (Thomas & Cantor,1978), a relationship which holds for both estimated and reproduced time (Zakay,1993b).

The essence of attentional models of subjective time was summarised by Michon (1978, p.106): "when absorbed by the task, no spare capacity is available to notice the passage of time, and consequently time seems to pass quickly; when the task is simple, much attention can be spent on time passing and time will be long." This can be expressed mathematically such that the duration of an interval is a monotonic function of the weighted average of information encoded by a temporal and a non-temporal information processor (Thomas & Cantor,1975; Thomas & Weaver,1975). This implication behind

this formulation is that there is a general pool of attenttional resources and the more effort demanded by a task, then the greater the attention allocated to so-called nontemporal information.

Many studies have confirmed a shortening of experienced duration when attention is focused on a nontemporal task (Fraisse,1979; Casini et al.,1992). Indeed, Tsang et al., (1996) have shown that task performance and time estimation represents a trade-off based on the extent to which two tasks share common processing resources. From a clinical perspective however, Thomas' model does not accommodate changes in arousal (especially important after brain injury) which are known to affect both attention and time experience. Recently, Zakay and Block (1996) have proposed that distribution of attention may be gated and that one factor influencing this gating mechanism is the relevance of time, (Rousseau and Rousseau (1996) proposed a similar account based on their animal work). This "attentional-gate" approach is compatible with an internal clock, by postulating that the attentional gate controls the registration of pulses in an accumulator (Zakay and Block (1996) re-name it a "cognitive timer"). It may prove a more generic and useful framework than previous attempts but it remains poorly specified in some key respects. Further discussion of this particular model is deferred until later in the thesis.

In general attentional accounts of psychological time have failed to take account of another common cognitive time distortion, namely that intervals seem longer if an individual is expecting an event to occur or is frustrated with waiting. There is sound experimental evidence that anticipation and expectancies serve to increase apparent duration. For example, Cahoon and Edwards (1980) reported that a four minute interval spent waiting for a pot to boil was overestimated relative to an equal interval of unspecified activity. Block et al., (1980) also asked subjects to watch for the moment when a vessel of water started to boil. In a condition where the water did not boil, subjects overestimated the duration of the experiment, whereas when the water boiled sooner than anticipated, subjects underestimated the time. Using a different paradigm,

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Boltz (1993) demonstrated that unexpectedly premature or delayed endings to musical compositions may exert a significant bias in temporal judgement (see below).

Studies such as these have given rise to what may be termed an 'ecological' approach to time estimation, which takes account of temporal dimensions such as the sequence of elements of a task and its temporal patterning (Boltz,1985). In fact, duration generally seems shorter when subjects are asked to estimate the duration of a task than when asked to attend to the passing of time (Hawkins & Telford,1976), which has led some theorists to suggest that the kind of information in an interval, rather than simply the quantity of information, might account for differences in apparent duration. In particular, they have investigated whether there is an implicit temporal patterning to activities that evokes expectations about when an interval should end. This approach has philosophical appeal as well as practical value, deriving its conceptual origins from Liebniz, and more recently from the ecological approach to cognition, which proposed that time is derived from events, not vice versa (Gibson,1975).

In this vein, Boltz (1985) and Jones and Boltz (1989) explored musical perception and showed that musical expertise is associated with the ability to perceive nested phrases in a score which approximate to "non-arbitrary temporal coherences." Musical compositions high in such temporal coherence permit anticipation of what comes next, and thus afford a "future-oriented" mode of attending. Jones et al., (1993) claim: "in terms of the filled interval phenomenon...if two time intervals both end as expected then they will be *correctly* judged as being equal in duration." Violations of such coherence (for example, the abrupt ending of a piece of music) cause momentary surprise, ('temporal contrasts') and, in comparison with a temporally coherent and more predictable piece of the same duration, will appear shorter. According to this Expectancy/contrast model abrupt ending (negative temporal contrast) leads to shorter duration whereas termination of an event later than expected (positive temporal contrast) causes an overestimation of time. This is really a re-statement of the fact that an event that appears to have ended prematurely establishes a conflict: either one's expectations

were violated, or time has gone quicker than it appeared. In cases of high temporal contrast it appears that we trust our expectations and thus underestimate duration. The wider adoption of this framework is still awaited but, in an effort to generalise the model, Boltz (1993) reported that subjects' who waited for a shorter time than they were led to expect underestimated the duration of the waiting period, while those who waited longer than expected (as well as those who were not given information upon which to base an expectancy) overestimated the interval. In an unusual recognition of the relevance of timing accuracy it was reported that subjects were most accurate when waiting time coincided with expectancies.

In summary, there is clear evidence that the experience of duration is affected by the amount of attention one pays to time, which is usually related to the demands of any concurrent activity. This is interpretable within a competitive notion of psychological time whereby task-related events and extraneous events compete for limited processing resources. Recent formulations incorporating the relevance of anticipation raise the suggestion that psychological time is not simply a data-driven phenomenon, but can be influenced by a variety of non-temporal factors such as mental set and expectation.

One feature of the attentional approach to time has been the introduction of the dichotomy between temporal and nontemporal information which has focused interest upon which aspects of a task contribute to a sense of subjective duration. As a result, task difficulty has been proposed as the main means by which attention to time can be manipulated. Certainly, if tasks are too difficult it appears that advance warning of the need to estimated time which characterises the prospective paradigm may be ineffective (Hicks et al.,1976). Unfortunately, the notion of task difficulty remains vague and is used inconsistently leading to confusions. For instance, the experienced duration of a given task may be less directly related to task difficulty and more a function of the sensitivity of the task to some particular process which is also utilised in timing such as short term memory (Fortin et al.,1993). There is also a danger of circularity of definition,

whereby temporal information is only distinguished from the non-temporal by virtue of being able to influence subjective duration.

Mainstream attentional accounts do not address the influence on subjective time of prior set or expectation, which has led to the development of a more 'ecological' approach. This has elicited evidence that time experience is an interactive process in which subjective duration is based on a combination of attended time, task effort and anticipated duration. Such an approach has potential to enrich clinical studies by providing a more comprehensive account of how people regulate their behaviour by within time constraints, thereby introducing an additional factor which might illuminate how this process could break down.

2.4 (ii) Memory and Psychological Time

Reference has already been made to William James' contribution to attentional accounts of psychological time with his observation that interesting experiences pass quickly by. However, James also acknowledged that such events are often remembered as longer than an equivalent empty interval, thus illustrating a common memory phenomenon which also needed explaining. Amongst theorists about psychological time, it has long been argued that such time distortions are better explained in terms of normal mental processes than biological clocks that speed up or slow down (Fraisse,1963; Friedman,1990). The effect which James recounted so succinctly has been investigated in a number of studies looking at how the number of events in an interval lengthens impressions of its duration. One of the most influential studies was reported by Ornstein (1969) who demonstrated that retrospectively estimated time spent scrutinising stimuli increased with the magnitude and complexity of the material. Furthermore, when the number of stimuli, rate of presentation and their organisation was manipulated subjects presented with the more highly organised stimuli gave longer duration estimates and as well as showing better memory for stimulus items (Vroon,1970; Block,1974). Although no casual relationship was demonstrated these studies suggested that improvements in memory for information presented in an interval were responsible for increased estimates

of duration. More recent studies have supported this view. In a memory task in which students were instructed to remember selected words from an auditorily-presented list, the estimated duration of the list increased when the critical words were interspersed with more non-critical words occurring in-between (Zakay et al.,1994). In fact, the time taken to present auditory word lists may be judged longer for common familiar words than for novel word lists (Hochhaus et al.,1991). This is generally interpreted as evidence that familiarity is associated with longer retrospective duration due to increased memory for events in an interval.

The plausible hypothesis that greater structural organisation of information in memory may underlie longer estimates of duration is also invoked to account for the otherwise conflicting finding that tasks utilising more complex stimuli may be judged shorter than simple tasks (Mulligan & Schiffman,1979). If simpler stimuli afford greater organisation in memory and are therefore more retrievable then estimated duration should be better. Conversely, there is also some evidence that remembered duration is shortened if information processing load can be reduced (Berg,1971; Miller et al.,1978) although Kowal (1987) failed to confirm this effect in vigilance tasks using semantically meaningful and meaningless material. Unfortunately, in the absence of any reference to the accuracy of time estimation it is not possible to draw unequivocal conclusion from these results.

Frankenhauser (1959) originally proposed an account of subjective duration on the basis of the nature of stimulus material, reporting that time experience lengthens with increasing rapid metronome beats in a given period. However, the most explicit account of remembered time in terms of the properties of long term memory was by Ornstein (1969). For obvious reasons his proposal came to be known as the storage-size hypothesis: "it takes more space to store new events, so that an increase in the number of events in an interval should increase storage size and lengthen the experience of duration of that interval" (p.105). The usefulness in a clinical context of the storage-size hypothesis is limited to considering the relation between memory impairment and

remembered duration (see chapter 9). Yet, despite the intuitive appeal of this model unequivocal empirical support for Ornstein's interpretation is scarce. Both Berg (1979) and Mulligan and Schiffman (1979) showed that the use of metacognitive schema to organise information was associated with shorter duration estimates but Berg (1979) only used intervals up to a maximum of three seconds. This accords with Michon's (1967) model of psychological time which shares similarities with Ornstein's account in terms of its reliance on limited capacity storage except that it purports only to account for short-term memory processes. Mulligan and Schiffman (1979) utilised a 60 second interval which was sensitive to long term memory (see also Ornstein,1986) but the authors acknowledged limitations in the generality of the storage-size account.

In fact, there are some key data which appear inconsistent with the theory as Ornstein proposed it. For instance, Underwood and Swain (1973) showed in a vigilance task that the estimated duration of intervals masked by noise was longer with higher intensity noise, even though less information was encoded (and remembered) during such periods. Vroon (1970) compared perceptual (input) rates of stimuli with motor responses (output) in terms of their influences on subjective duration. As predicted by Ornstein's model, duration judgements increased proportional to the amount of presented information. However, increasing the rate of stimulus presentation did not increase duration estimates. Furthermore, increasing the information transmission rate (subject response) actually led to shorter time estimates, perhaps because greater activity on the part of the subjects was not processed as part of the stimulus information on which judgement of remembered time was based.

A significant conceptual development was brought about in the 1970s by a series of studies in Montana by Block and his colleagues. In direct contradiction to a storage size explanation of duration, Block (1974) and Block and Reed (1978) reported that levels of processing in memory did not affect remembered time, but a task involving switches between judgements of semantic (deep) and visual (shallow) similarity was associated with longer retrospectively estimated duration. This hitherto unexpected result was

interpreted in terms of the critical role of *changes* in information processing demands upon subjective duration.

The effect was replicated with nonverbal stimuli by Block (1978). Subjects' judgements of stimulus inspection times was unrelated to their memorisation complexity. However, when the stimuli were administered in orderly spatio-temporal sequence rather than randomly, then greater sequence complexity was associated with longer duration estimates by subjects, despite both sets of stimuli being equally recognisable. Block (1978) argued that this outcome requires consideration of the arrangement of stimulus elements in time and is not predicted by traditional memory-based theories which relate subjective duration directly to memory for individual elements. In this way Block (1978;1990b) avoided any circularity inherent in the notion that changes in events constitute events themselves, by proposing that changes in events represent the context within which actual events occur. According to the 'contextual change hypothesis' which he advocated on the basis of these experiments, remembered duration is based on memory for changes in context, rather than memory for overall stimulus events. It is worth noting that, from a conceptual perspective, this proposal is reminiscent of the philosophy of Liebniz and psychology of Fraisse, and it re-asserts a significant assumption about psychological time which underpins the present research thesis, namely that, insofar as it has any meaning as a psychological construct, time comprises changes in events.

Thus far the results emanating from studies of remembered duration have been recounted within the cognitive frameworks in which they were originally undertaken. Although many such studies were conceived in cognitive fashion directly because of the perceived inadequacies of current physiological timer models, the same data can be massaged to fit the internal clock mould. For example, there is no a priori reason why the number of events in an interval should not affect the rate of an internal clock, though animal studies suggest that transfer of pulses from a putative pacemaker to a hypothetical accumulator may in fact be gated. Plausibly one might speculate that this gating process is capable of

being affected by the nature of any external stimulation in an interval. Most internal clocks have a memory stage in which it is hypothesised are stored previously sampled representations of time intervals, against which to compare the present period. In terms of the storage-size analogy, it is equally viable that just such a pre-sampled interval t which contained, say $x + y$ events in memory, may bias the interpretation of another interval t' containing x events and distort comparison of two periods with the result that t is judged to be longer than t'.

It is clear on reviewing the literature that the inability of investigators to control for the multitude of experimental variations in stimuli, time interval and method of time estimation has clouded similarities between models. An early conceptual resolution of this impasse was attempted by Hogan (1978). He proposed that the relation between activity and estimated time was essentially curvilinear, whereby subjective duration diminishes from simple to optimum complexity, but increases again with greater task difficulty. To date, this speculative integration has not been subject to any empirical test. However, the critical aspect for many contextual theorists is that time depends on awareness of changes in context, rather than immediate variables such as task difficulty. For example, Fraisse (1973) studied an individual living in a deep underground cave. His average estimates of the time between waking and his lunchtime meal were under five hours, whereas the mean clock duration was over ten hours. This marked underestimation of time was attributed by Fraisse to the poverty of contextual changes in the subject's life of deprivation. Interestingly, this man also consistently underestimated duration of between 30 and 120 seconds, suggesting some continuity between the processes employed in estimating short intervals, of the kind used in experimental studies, and the more ecologically meaningful intervals to which the results are sometimes extrapolated.

In trying to interpret the validity of different models of retrospective duration, one encounters as many areas of potential concordance as of apparent dispute. Both the more recent developments of internal clock models and the cognitive accounts of subjective

duration hold that psychological time is underpinned by the apprehension of events, or more particularly by awareness of change between events (though some philosophical accounts hold that the only true events are those which signify change between two otherwise identical states, hence change itself is the event). As reviewed in chapter 1, this notion has a long history, and offers a common basis for any conceptual reconciliation of theories of remembered time. If the occurrence of events is the basis for change, then Ornstein's emphasis on new events is compatible with Block's model under some conditions. Speculatively, one might suggest that whether registration of stimulus events themselves underlies subjective time or whether it is based on contextual processing depends on the task demands. Detailed predictions of such a hybrid position have not been addressed by any studies to date and therefore the suggestion remains vague. Nevertheless, some notion of the kind of study required to address this problem was reported fairly recently by Martinez (1992), seeming to demonstrate an interaction between experimental paradigm and processing strategy. A contextually-based derivation of duration seemed to account for prospectively estimated time, but when attention to time was only incidental (in retrospective conditions) the degree of effort involved in the tasks appeared to affect the judged duration.

In another attempt at combining theoretical approaches, Glicksohn et al., (1992) proposed the idea of an internal clock operating within certain contextual limitations, making use of the somewhat ambiguous notion of a "cognitive-timer". Still more recently, Block and Zakay (1996) have suggested that the contextual approach could be accommodated within a modified internal clock framework, so long as a pacemaker or pulse generator were functioned as a "context-generator" and the timer and comparison processes were responsible for registering and comparing contextual information.

In summary, the notion that some forms of contextual information mediate temporal experience is supported by a variety of experimental data, although the extent to which such 'hard cognitive' data are incompatible with the increasingly pliable internal clock concept is unclear. Like other cognitive theories about time, the contextual account does

not account for all the evidence. It remains to be demonstrated that this is a useful working framework, but it has the potential for integration with other studies of context in cognition, especially memory. Presently the concept of context is rather too broad and only very general predictions have been made about the influence of contextual information on psychological time. Although it has the potential for wide-ranging application, so far studies have not addressed time experience in functional situations, or in a clinical population. These issues are explored in later chapters.

2.4 (iii) Executive skills and psychological time

The role of executive functions in subjective time experience is a vastly neglected area of research in the psychology of time. This is principally because most of the cognitive studies of time are traditional laboratory-based experiments which are not designed to utilise executive skills, while the literature on executive abilities has generally considered time as an independent variable, not a subject of study in itself. Yet, given our increasing appreciation of executive contributions to memory and especially to attention (Baddeley & Weiskrantz, 1993) there would seem to be fruitful grounds for exploring this aspect of psychological time. Moreover, if subjective time experience is an adaptive capability, allowing individuals to regulate their behaviour according to contingencies in the environment, then the study of executive aspects of psychological time would seem to be of particular relevance.

As far as some of the more purely experimental studies are concerned, one has to raise questions about their ecological validity in so far as they are likely to be sensitive to executive aspects of psychological time. For instance, they have been justly criticised on the grounds of the artificial nature of many of the stimuli employed (Fraisse,1984). Despite this weakness many recent experimental investigations seem to produce results that are broadly in keeping with older literatures on organisational and ergonomic aspects of temporal behaviour, the latter perhaps being more sensitive to executive functioning as they are less constrained by the demands of experimental rigour. For example, Schiffman & Greist-Bousquet's (1992) demonstration that task interruptions are

associated with increased perceived duration is entirely consistent with Harton's (1942) ergonomic demonstration that subjects lengthen their estimates of duration when an interval is spent doing several tasks rather than pursuing a single goal. Unfortunately, few investigators appear to be interested in risking their experimentally-obtained results by testing their generalisability within a much broader frame of reference. One of the most notable exceptions has been the research conducted by Boltz (1985) and her colleagues, from which they developed the Expectancy/contrast model (see section 2.4 (i) above).

There is one additional aspect of the psychological study of time however, which reflects the significance of a facet which may be subsumed under the term executive functioning. This concerns the relevance of subjective utilities in behavioural control. On the basis of the preceding discussions about the nature of subjective duration, it seems plausible that the importance of subjective utilities or goals in behavioural regulation is likely to have significant influence on how time is experienced. There is supportive data from comparative studies which suggest that an internal clock times stimuli on the basis of signal value, ie. associative strength (Roberts & Holder,1984). Given that temporal processing is at least partially an effortful endeavour, it seems highly likely that processing resources will be made available according to perceived importance (Michon & Jackson,1984). Certainly effective time-allocation is an essential aspect of planning in effective problem solving. As an illustration of this, Buehler et al., (1994) demonstrated in a sample of 465 undergraduates that poor planning arises because self-allocated time for task completion tends to be based on expectancy rather than past experience.

Despite the argument that executive skills may have a crucial role in psychological time (in the way behaviour is generally guided by time constraints in everyday life), there is little explicit recognition of this in models of psychological time. In this context, one particular theoretical contribution stands out as having potential for exploring the role of executive functions for time experience. Zakay (1992) has proposed that the importance assigned to time in a specific problem solving situation (which he termed 'temporal

relevance') affects the tolerable degree of ambiguity associated with an event's duration (known as 'temporal uncertainty'). In this context, temporal relevance is the subjective utility attached to time in a specific state requiring optimal adaptation to the environment, and as such "is a dynamic parameter whose level is under continuous change," (Zakay (1992) pg.110). Temporal uncertainty is a level of subjective predictability based on past experience, prior knowledge and anticipation.

The idea that the importance of time constraints varies across tasks is one which experimental studies have long been demonstrating without necessarily appreciating the broader relevance of this observation. Thus retrospective time estimation studies generally yield shorter estimates of subjective duration than do prospective judgements, simply because in the former paradigm subjects are not pre-warned about the need to attend to time. In other words, the relevance of time to the task at hand is negated.

Since Zakay proposed his notion of temporal relevance there have been no attempts to specify more precisely the parameters within which the hypothesised subjective utilities operate. Still, preliminary experiments suggested that the concept could have significant clinical relevance as they demonstrated that longer prospective estimates (implying greater attention to time) occurred under conditions of greater temporal relevance. This is the essence of efficient, successful problem solving - avoid running out of time.

Summary

Despite the pre-eminence of the internal clock concept for much of the history of research into psychological time, there is now considerable evidence that the experience of time is not modulated by an automaton clock. The diversity and richness of human temporal experience points at least to very significant mediating contributions from attention and memory. In addition, increasing recognition within the mainstream cognitive arena of the executive modulation of some attentional and memory systems suggests that executive functions should play an important role in time experience in everyday life. To some extent this has been anticipated by theorists who have argued that

psychological time is critically influenced by 'top-down' influences such as prior belief and mental set (Boltz,1985) and the importance of subjective utilities and the perceived relevance of time (Zakay,1992).

Attempts have periodically been made to reconcile the results of cognitive studies of time with an internal clock position (Thomas & Cantor,1975; Glicksohn et al.,1992; Block & Zakay,1996). This has entailed that temporal information is effortfully encoded (Yntema & Trask,1963), a notion which itself has been criticised (Tzeng,1979). However, the main evidence that temporal information is automatically encoded comes from studies of temporal order (Hasher & Zacks,1979) rather than of experienced duration. Thus there are grounds for considering the role of effortful processing of temporal information within internal clock frameworks as well as from cognitive perspectives. The different approaches of investigators have contributed to the confusions; memory researchers have tended to emphasise automaticity whereas psychologists studying time have argued for effortful processing.

Support for proponents of the modified internal clock has been received from animal studies suggesting, for example, that attention can influence the accumulation of pulses from an internal clock (Meck,1984). However, as internal clock models increasingly incorporate cognitive constructs - witness the notion of a 'cognitive timer' used by Glicksohn et al.,(1992) and Zakay (1993b) - it becomes less appropriate to simply see them as two dichotomous classes of theories of psychological time. Instead they may function as different levels of description, applicable to different kinds of phenomena. Internal clocks are generally proposed as descriptions of timing, usually of fairly simple actions, and are not identified with introspection. Nevertheless a fundamental difference between the approaches remains concerning the status of a complex specialised timing system, the more accurate description of which now sees internal clock theorists making use of cognitive terminology. In contrast, cognitive theorists seek to explain and predict time experience by appeal to existing information processing systems.

In the following chapters the nature of subjective time disturbances after brain injury will be explored with particular emphasis on the role of attention, memory and executive skills. Where appropriate, attention will be drawn to the explanatory adequacy of cognitive and internal clock accounts. This will be preceded however by an account of the problems of time organisation in clinical populations which will provide the foundation for the empirical investigations which follow in subsequent chapters.

Chapter 3

Time disturbance in clinical states

Although temporal aspects of memory such as lag and order have been widely studied in clinical groups (Squire et al, 1981; Milner, 1985; Parkin & Hunkin,1993), other aspects of cognition which might be expected to underlie psychological time after brain injury, such as experienced duration, have received relatively little attention. This omission is all the more surprising as there is an established psychiatric literature on this subject and it is widely recognised that time estimation is sensitive to general intellectual capabilities (Tsukanov,1991; Grskovic et al.,1995). The absence of a literature on anomalies of all manner of facets of psychological time is also regrettable since clinical experience suggests that disruptions to the temporally-organised nature of behaviour appear to accompany and possibly underlie many of the functional deficits associated with severe brain damage. In the following section the principal observations of time distortions associated with mental disorder and brain injury will be discussed in so far as they substantiate psychological theories or bear upon a general understanding of anomalous time experience.

Practising clinicians are regularly confronted with a wide range of problems with respect to time. These include disorientation in time, deficient allocation of time to tasks, poor appreciation of the passage of time, and inability to tell the time. In rehabilitation these aspects of time inter-relate as they are all central to the complex manner in which action is organised in temporal contexts. However, in neuropsychological terms these different strands of psychological time pertain to different cognitive abilities. Furthermore, the investigation of psychological time associated with various cognitive deficits has been impeded by the absence of a consensus about normal time experience. This leaves clinicians with no conceptual framework within which to investigate temporal abnormalities. Initially therefore, it is necessary to develop a working model of temporal experience to encompass many of the phenomena associated with the subjective sense of

temporal passage. Moreover, (in order to facilitate resumption of its central aspect in human cognition) such a model must be amenable to translation into the vernacular of current information processing psychology, specifically in terms of memory, attentional and executive processes, as well as being able to assimilate the social context of the resulting disabilities.

In the present chapter disturbances of temporal experience will be considered in relation to four key aspects of cognition: attention, episodic memory, semantic memory, and executive skills. Evidence that deficits in these areas have implications for psychological time will be discussed, as this structure will reflect the organisation of the thesis as a whole. Later chapters will then examine temporal disturbances in severely brain damaged patients in the context of their neuropsychological deficits.

3.1 Mood and temporal awareness

Disturbance of the personal experience of time is associated with a variety of mood disorders (Sims,1995). For example, Chattopadhyay et al. (1980) and Zabrodin et al. (1983) reported increases in judged duration with elevated anxiety, consistent with Watts and Sharrock (1984) who found that spider phobics overestimated time spent observing a spider. Time estimation can also be modified and made more accurate by increasing or reducing anxiety (Zabrodin et al.,1983). Longitudinal studies confirm a relation between periods of low mood and poor time estimation (Richter & Benzehofer,1985), with negative affect associated with underestimates of time and over-estimation of time being reportedly common in manic states (Tysk,1985). One explanation which might account for this variation is possible within an internal clock framework on the basis of a disturbance to a putative pulse generator or pacemaker. This would suggest that depression is associated with a reduction in the pace of internally generated pulses which forms the basis of timing, whereas elevated mood results in a quickening of pulse generator output. Unfortunately for such a hypothesis, depressed patients often report that time passes slowly, which would suggest a faster rate of subjective time (ie. an

increase in pacemaker rate), which would yield over-estimates of time. Obviously unequivocal generalisation are unrealistic at this stage, the research on psychiatric samples being confounded by different time estimation methodologies, medication regimes and the possible generalised effects of psychomotor retardation (Kitamura and Kumar,1983).

In terms of the contribution of affective states to timing mechanisms, these issues have not been specifically addressed by internal clock models; any attempt to do so necessitates extrapolating hazardously from recognised influences such as the associative strength of stimulus associations. Likewise cognitive theories have generally not taken mood into account. For these reasons, and because the clinical population from which subjects for the present research were taken is so severely cognitively disturbed, for the purposes of examining the cognitive underpinnings of psychological time, affective factors will not be addressed specifically in the thesis.

3.2 The cognitive organisation of psychological time

This section will comprise a review of reported disturbances of psychological time associated with brain dysfunction in terms of the likely constituent cognitive processes, attention, memory and executive skills, which were highlighted in chapter 2. Although most of the relevant clinical studies were conducted atheoretically, particular emphasis will be placed on interpreting the results in the context of the models of psychological time that were reviewed in chapter 2.

3.3 Attention and the experience of duration

Time experience is given scant attention in several key works on memory and cognition (eg. Tulving & Donaldson, 1972; Parkin & Leng,1993; Kapur, 1994; Parkin,1996). Despite this neglect more recent research is highlighting the importance of temporal aspects of cognitive disturbance. For example, it has been argued that the organic confusional state appears to be primarily a disorder of temporal context (Schnider et

al.,1996). Many neurologically-impaired patients report a sense of bewilderment at the passage of time but, however tantalising such subjective reports are to the clinician, phenomenology is not a popular research methodology in neuropsychology. In the absence of a recognised neuropsychological account, the concept of psychological time as it is pursued in the thesis will be examined in terms of likely cognitive constituents for which there are already well-established models. The present section considers specifically the role of attention underpinning psychological time.

The crucial role that attention plays in mediating concurrent awareness was recognised by Locke and later William James. Attention as a potential moderator of subjective timing is recognised in many second generation internal clock models (Thomas & Weaver,1975; Thomas & Cantor,1978) as well as by cognitive accounts (eg. Block,1978; Jackson,1990; Boltz,1991). The evidence for attentional models of psychological time which was reviewed in chapter 2 reveals a general ignorance of relevant neuropsychological data, and conversely, the few human clinical studies of attention to time have been mostly atheoretical. This is regrettable as the comparative research has been moving for some time towards integration of the cognitive and internal clock models, a shift illustrated by Meck's (1984) demonstration that registration of pulses emitted by a putative pacemaker could be influenced by attention.

Within the psychiatric domain there are intriguing suggestions of cognitive factors affecting time estimation, especially from schizophrenic patients who anecdotally are reported to show disturbed time awareness in various forms (Sims,1995). In contrast with the data from brain-injured groups which shows a general tendency towards underestimation of tasks, various groups of schizophrenic patients have been shown to underestimate short intervals of up to 1.5 seconds (Chattopadhyay et al.,1980) and to over-estimate intervals of 30 seconds relative to non-psychiatric controls (Tysk,1983a) and other psychiatric groups (Densen,1977). Over-estimation of time intervals has also been reported in longitudinal studies of schizophrenics (Tysk,1984) though with no

relation to diagnostic subgroups (Tysk 1983b). Discussion of the possible effects of medication are surprisingly absent from the majority of such studies.

Neuropsychologically the literature on time disturbances in schizophrenia is particularly interesting because of the suggestion of associated frontal lobe dysfunction (Weinberger et al.,1991; Pantelis & Nelson,1994) which has contributed to the hypothesis that the illness may be characterised by inability to form and maintain contextual associations (Cohen & Servan-Schreiber,1992). In keeping with results from comparative studies which suggest that internal timing processes are modulated by dopaminergic systems, overestimation of time by schizophrenics may be reduced with neuroleptics (Wahl & Sieg,1980). Nevertheless, given the difficulties in parsimoniously characterising the diversity of schizophrenic symptomatology, it is perhaps not surprising that time disturbance in schizophrenic states has not been conceptualised in terms of a dysfunction of internal timing mechanisms. In fact, the majority of chronically-ill psychiatric patients are likely to be generally disoriented in time (Joslyn & Hutzell,1979) and, as Aubrey Lewis (1932) remarked: "disorder of time consciousness . . . may be found almost as often as it is looked for in mental disorder." In general therefore, psychiatric studies have regarded temporal disturbance as secondary to disordered thinking (Doob,1971).

One interesting exception is the case of slowness in obsessional-compulsive disorder (OCD) which is not held to be secondary to ritualistic behaviour or fear of aversive consequences (Rachman,1974; Takeuchi et al.,1997). Primary obsessional slowness is characterised by an apparent meticulousness in performing daily tasks, although individual acts can be initiated. Toates' (1992) semi-autobiographical account suggests it marks an inability to reach a criterion to stop an activity. Consistent with this supposition, evoked potential and PET investigations have shown areas of hyperactivity in orbito-frontal and midfrontal cortex (Malloy, 1987; Sawle et al.,1991). There is some evidence that these areas are involved in preparation of self-initiated movement (Passingham,1993) and therefore OCD patients may be showing increased internal action planning. Baxter et al., (1996) have speculated that this is perhaps due to reduced

inhibitory GABA efflux from the basal ganglia to structures responsible for ensuring behaviour is interrupted at the appropriate time. Yet, although a putative fronto-basal ganglia dysfunction in OCD (Hymas et al.,1991) could give rise to a deficit in suppressing action-schema, and therefore could conceivably affect the timing of action, it does not appear to impede the subjective appreciation of clock time. Time estimation studies show no clear abnormalities, despite subjective reports from sufferers that they may lose all track of time while engaged in rituals (Rachman & Hodgson,1980). It is clear that studies conducted to date with subjects drawn from psychiatric populations are beset by conceptual and methodological difficulties. As a consequence they have little informative contribution to make at this stage to the development of a neuropsychological account of psychological time. Therefore the rest of this section, and indeed the chapter, will be devoted to considering the relevance of evidence gathered from primary brain injury cases.

3.3 (i) Attention, temporal order and Psychological Time

One important aspect of the role of attention concerns the effortful or automatic manner that information relevant to the experience of time is processed. As mentioned in chapter 2, most evidence for automatic processing of temporal information is derived from studies of temporal order aspects of memory, information which is purported to be encoded along with stimulus details at presentation. In fact several theories of psychological time have been proposed on the basis that temporal aspects of information are encoded along with the information itself (Yntema & Trask,1963; Berlyne,1966; Murdock,1974), although not all of them assume that such temporal information is registered effortlessly. Indeed effortful encoding of temporal information provides the basis for the attentional theories of psychological time previously discussed in chapter 2. Certainly there are grounds to suspect that attention to temporal context may contribute uniquely to the experience of duration. Casini et al. (1992) demonstrated that attention to a temporal information processing task (stimulus duration judgement) interfered with a non-temporal task (stimulus semantic categorisation) to a greater extent than attention to the non-temporal task affected concurrent duration judgement.

Clinically, impaired registration of temporal order may occur with anterograde amnesia (Hurst & Volpe,1982; Bowers et al.,1988; Kesner et al.,1994) and also appears to be associated with frontal (Milner,1971; Milner et al.,1991) or thalamic damage (Parkin et al.,1994; Shuren et al.,1997). As mentioned above, Schnider et al. (1996) proposed a defect of temporal order to account for organic disorientation, and even healthy disoriented subjects show poor time estimation (Dunne,1934; Macleod & Roff,1936). Temporal order information is particularly vulnerable in normal controls (Squire et al.,1981) but as yet there has been no attempt to suggest that temporal order (which may be less susceptible to attentional mediation than other aspects of psychological time) actually underlies estimated duration.

The notion that temporal context as order may form the basis of subjective duration has some appeal for its simplicity as much as anything else in a field beset by complexity and ambiguity. Yet despite some justification for this view, most theoretical models of time experience treat temporal order and duration quite separately, without addressing the question of their inter-relationship. In fact this relation may well be more complex in clinical cases than the comparative animal data suggest as impaired temporal ordering is not sufficient for disorientation (Wiegersma et al.,1990; Milner et al.,1991) and severity of temporal order deficits does not predict degree of disorientation (Shimamura et al.,1991).

One accessible means of testing the contention that temporal order information is also used to provide the basis for duration judgement is to use a recency memory paradigm. Recency memory is one of the most robust temporal memory phenomena (Milner,1971), impairments of which are known to be associated with frontal lobe damage (Shimamura et al.,1990), especially dorsolateral prefrontal cortex (McAndrews & Milner,1991). It is also recognised that material-specific recency memory deficits can follow lateralised frontal lesions (Milner et al.,1991). In undertaking such a study with neurologically-impaired subjects however, it is important to distinguish the contribution that poor

recency memory could make to subjective duration from the effect of a general anterograde memory deficit. One way to manage this is to minimise the general memory load and optimise the role of temporal order information, by making the time estimation task a prospective activity. In other words, by forewarning the subject of the need to attend to time throughout the task, an attempt is made to ensure that the subsequent duration estimation is not based on memory for the interval, but on concurrent monitoring during task activity, thereby making the task more sensitive to attention.

No such study has been conducted previously, although Vakil et al., (1991) reported in a head-injured group of unspecified severity that recall of temporal order information was inferior to controls when its retrieval required more effort (ie. when subjects were told to attend to stimulus order). This is consistent with the notion that temporal information processing is effortful (Jackson,1990) and suggests that recency judgements require effortful processing and are amenable to facilitation with provision of appropriate cues (McAndrews & Milner,1991).

However, poor recency memory does not consistently correlate with psychometric indices of frontal impairment in either Wernicke-Korsakoff cases (Hunkin & Parkin,1993; Parkin & Leng,1993) or diencephalic lesions (Parkin & Hunkin,1993). Recent evidence suggests that dorsolateral prefrontal involvement may play a critical role in this relationship (Kopelman,1997). Although this is a central concern for many memory researchers, the absence of any contribution from investigators interested in time has meant that little consideration has been given to the potential for exploring the relation between temporal memory and duration. Hence it remains unknown whether duration is derived specifically from temporal information (event order) rather than item information (event occurrence). Although evidence that subjective duration was directly related to temporal information would be consistent with the contextualist position, animal studies suggest (Roitblat & Young,1990) that order may be represented either by trace strength (analogous to recency) or by tagging with regard to an inner clock (based on event occurrence). The discrimination of a sequence of events then becomes a basis

for inferring both temporal order and the duration of an interval. This issue is addressed in a group study reported in chapter 4.

3.3 (ii) Attention, temporal coherence and Psychological Time

In contrast to the prevailing experimental bias of the previous section, many authors from a social and anthropological perspective have emphasised the way that temporal rhythms and patterns modulate and define activity (Doob,1971; McGrath,1988; Whitrow,1988). From such an "ecological" perspective Jones and Boltz (1989) developed their model of expectancy/contrast by which natural events have an internal structure which sets expectancies about their duration (see chapter 2). Another way to consider intrinsic temporal structure is in terms of the internal organisation of an event or series of events from which expectancies about duration are derived. This has not been explicitly proposed in this manner before but the term 'temporal coherence' seems appropriate. This is a novel term which is introduced to account for some of the many ways in which the structure or organisation of events in an interval appears to influence its estimated duration. For example, in chapter 2 it was discussed how evidence of the effect of stimulus organisation led to the storage-size and contextual-change accounts of psychological time. Temporal coherence may therefore be considered a form of intrinsic context (Mandler,1980) as it is an integral aspect of any interval of time. Of course, the nature of temporal coherence will depend on the specific spatio-temporal arrangement of stimuli in an interval, while the events themselves could in principle be presented in a manner which gives a different temporal structure to the period in which they occurred. The need to introduce a new term at this stage is established by the demands that any account of psychological time should encompass results derived from more than one conceptual or methodological orientation. This is not to deny that the importance of 'temporal coherence' was amongst the earliest of experimental psychological observations.

Since Bartlett's early memory experiments it has been recognised that the manner in which information is interpreted is dependent on its presentation form (Fentress &

Wickham,1992). However, temporal coherence as it is described above is also to be found in episodic recollections. As discussed in the previous section, brain injured patients have been shown to have difficulty encoding temporal relations between events (Hurst & Volpe,1982). This has often been attributed to diencephalic dysfunction (Shimamura et al.,1990; Parkin et al.,1990) though interestingly, non-Korsakoff amnesics with diencephalic lesions may not show this deficit (Squire et al.,1981). Nonetheless some forms of cerebral pathology implicating fronto-thalamic regions certainly appear to be associated with poor memory for temporal order (see also Milner, 1971; Milner et al.,1985). It seems likely that in the highly ordered and causal Western world appreciation of temporal regularity is fundamental to effective action. As temporal order is intrinsic to Western narrative, it may be conceived as a form of the natural temporal coherence which according to Jones and Boltz (1989) underlies duration expectancies. Moreover, as events can be re-told in many a different order from which they would naturally have occurred, temporal coherence is likely to vary depending on the structure of the narrative. Chapter 5 is therefore concerned with two issues: firstly, how the temporal structure of an interval may facilitate information processing, and furthermore, whether subjective duration is related to memory for constituent events or is directly derived from the temporal structure of an interval itself.

With regard to the first matter of how information processing may be influenced by the organisation of an interval, this is addressed using an auditory-verbal recall task in which the temporal structure of the stimulus material is amenable to analysis within the terms of a conventional account of textual processing. In their text comprehension model Kintsch & van Dijk (1978) proposed that coherence within a story is analysed in terms of co-reference and relationships between adjacent sentences which establishes a set of *macropropositions* constituting the gist of a text. Only three or so such propositions are sustainable in a working memory buffer, and according to van Dijk and Kintsch (1983), attempts are made to integrate buffer contents. This occurs firstly with incoming information on the basis of overlap, and if this is unsuccessful, on the basis of information from long term memory. Thus when the story details follow an orderly

sequence macropropositions are consistently supported by incoming information and are retained through successive cycles of processing. This not only promotes comprehension (and memory) for theme and plot, but facilitates processing of lower level actions embedded within. Thus temporal coherence may be seen to be compatible with cognitive models of discourse comprehension. Investigation of these mechanisms in a clinical context would be particularly interesting as impaired verbal recall of narrative information often follows brain injury (Richardson,1990; Parkin & Leng,1993) and yet the impact on memory of the organisation of auditory-verbal material is not well understood.

The second matter for consideration relates to the potential for judged duration to be susceptible to the intrinsic temporality of information presented during an interval. It is widely recognised that estimated duration is reduced by the employment of organising strategies (Berg,1979; Mulligan & Schiffman,1979) and event structure is one factor which can produce this effect, by apparently modifying information processing load (Macar,1996). Temporal coherence may therefore be conceptualised as an organising framework for information processing. Greater temporal coherence would thus be associated with shorter estimated event durations, assuming that intrinsic temporal structure mediates information processing within the limits of working memory (Fortin et al.,1993). Therefore consideration of the internal structure an interval suggests another means to consider the relation between memory for events and the experience of duration, and may offer new insights into recall of narrative information after brain injury.

3.3 (iii) Attention, task interruptions and changes in information processing

There is now a strong body of evidence from timing tasks demonstrating that attention is allocated preferentially to tasks or to task duration, according to the perceived task demands. A characteristic study which showed this trade-off was reported by Brown & West (1990) who showed that accuracy of stimulus duration estimates reduced with increasing numbers of target stimuli.

From a cognitive neuropsychological perspective, Norman and Shallice's (1986) model of executive control posits a Supervisory Attentional System (SAS) which is responsible for modulating the selection of action by controlling the allocation of attention. Given that attention is a limited resource, it follows that dual task performance (like paying attention to time while carrying out a task) inevitably involves some compromises. In the Norman and Shallice view this process is regulated by the activity of the SAS.

Although there have been no clinical demonstrations of this effect on estimated duration in clinical groups, comparative data suggest that the process of dividing attention between stimulus duration and stimulus presence is disrupted with lesions to the frontal regions but not by hippocampal lesions (Olton et al.,1988). This is certainly consistent with the Norman and Shallice position that the SAS is mediated by frontal lobe structures and forms the substrate for a mechanism by which on-going behaviour is interrupted following a trigger and replaced by a more appropriate action (Shallice & Burgess,1991). PET studies appear to confirm this by suggesting the existence of an attentional system mediated by the cingulate gyrus which is responsible for effortful attending and a second anterior system centred on the right frontal area which is active in vigilance tasks (Pardo et al.,1990; Posner & Rothbart,1991; Posner & Dehaene,1994; Rueckert & Grafman,1996).

It has already been noted that task interruptions are an effective paradigm for demonstrating the effects of attentional switching on time estimation in normals (Schiffman & Greist-Bousquet, 1992). Given the established difficulty amongst head-injured subjects in attentional switching (Brouwer at al.,1989; Azouvi et al.,1996), it follows that completion of interrupted tasks should be especially difficult for closed head-injured patients as such injuries are associated with anterior brain damage (Mattison & Levin, 1990). Hence neuropsychological notions of attentional control over behaviour form the conceptual basis for the empirical investigations of attentional influences on time estimation.

The influence of task interruptions with minimal additional information load on concurrent monitoring of time is investigated for the first time in a clinical sample in chapter 6. Chapter 7, by contrast, reports an experimental study with an emphasis on changes in information processing demands, difficulties with which have been widely associated with anterior brain damage (Wang,1987). Using a card sorting paradigm derived from Milner (1964) chapter 7 sets out to examine cognitive models of time which suggest that changes in information processing, rather than switches in attention underlie time estimation. In contrast to the studies described in chapter 6, the experiment reported in chapter 7 does not entail that attention is switched between tasks, instead it remains fixed on a single task (in addition to the need to monitor time). Thus in this task attention is employed only so far as to trigger a change in response set.

3.4 Memory and remembered duration

In contrast to Mediaeval notions of psychological time which emphasised the reality of the present, more recent cognitive conceptualisations have focused also on the role of memory in the maintenance of subjective time (see chapter 1 for the philosophical basis of this approach). As recounted in chapter 2, the first truly cognitive account of psychological time was Ornstein's (1969) storage size metaphor which was to some extent superceded by Block's (1978) contextual change model, both of which related duration to storage in long-term memory. Later developments in cognitive theories such as the expectancy/contrast model (Boltz,1985) which emphasises anticipations of duration, and Zakay's (1992) account of 'temporal certainty' also highlighted how past experiences of time in could influence presently experienced duration. From these important conceptual developments if is clear that an account of psychological time based solely on considerations of attentional factors is much impoverished. Notwithstanding the fact that these two crucial aspect of psychological time have been artificially separated for experimental purposes, in reality the reciprocal influences of attention to time and memory for time are virtually inseparable. It is particularly important therefore, when considering disturbances caused by brain injury, that the multi-

faceted nature of mnestic contributions to psychological time are acknowledged. The following section raises some of these important issues which will be investigated in later chapters.

3.4 (i) Retrograde memory and the temporal context of past events

An important aspect of the ability to think and act in temporal terms is the representation of past events. Indeed for the memory of any past event to be useful it must be associated with a temporal context (Olton,1989). Persons may have particular difficulties with various aspects of temporal context such as identifying famous people as dead or alive (Stevens,1979) or recalling events from specific periods of their lives (Kopelman et al.,1989). Context such as this tends to be associated with recall of specific events and may occur in the presence of a focal retrograde memory loss (Kapur et al.,1992) or as part of a global amnesic syndrome (Dalla Barba et al.,1993). However, at least one form of temporal context, namely temporal discrimination, does not seem so intimately related to memory for the event itself and can therefore be selectively spared or impaired. For example, Sagar et al (1990) demonstrated that the amnesic HM could show normal temporal discrimination for items even when his recognition memory for the actual stimuli was impaired. HM could retain this kind of temporal information in the context of bilateral medial temporal lobe resections (Scoville & Milner,1957). In contrast to HM, the converse pattern of impaired memory for temporal order in the context of preserved memory for the actual items has been reported following lesion of the diencephalon (Parkin & Hunkin,1993; Hunkin et al.,1994) and frontal lobes (Parkin et al.,1988). Other cerebral regions may also be implicated in poor memory for temporal order (Kopelman,1989) but it appears that medial temporal structures such as those which were lesioned in HM]h are not involved (Hunkin et al.,1994). Thus it seems that memory loss for autobiographical events is particularly associated with temporal lobe damage (Kapur,1997) but such circumscribed pathology is not sufficient to disrupt temporal order memory.

Time therefore appears to be reflected in memory for past events in at least two distinct ways. Firstly, events are dated and ordered. This may be on a standard time-scale (eg. AD. 1066, November 5th) or in terms of relative recency (event X being earlier or later than event Y). Kemp (1988) suggested that this dating process is carried out by a reconstructive process rather than by cues relating to the age of a memory or time of its formation. In fact, for public events estimations of event duration correlate only weakly with event knowledge (Burt & Kemp,1991) and not at all for autobiographical events (Burt,1992), somewhat contrary to the storage-size hypothesis of remembered duration.

The second means of representing the temporal context of an event is in terms of the organisation of episodic memory (Tulving,1987). Neuropsychological evidence of fractionating memory systems has been singularly influential in this regard (Baddeley,1982; Squire & Zola-Morgan,1988), and clinical case studies in particular have been instrumental in elucidating the complex organisation of information in memory (Parkin,1997). Of especial relevance to the present concern with the organisation of event memory is the model proposed by Hodges and McCarthy (1993; 1995). These authors suggested that specific memory records such as semantic knowledge or episodic fragments may be indexed in terms of pre-eminent themes by 'thematic frameworks.' One such mode of thematic organisation is in terms of the temporal context of events, so that events may be indexed according to specific periods of a person's life. This model arose from the analysis of a patient with bilateral thalamic damage who exhibited marked confabulation for autobiographical events (Hodges & McCarthy,1993). The patient's event memory was severely disrupted in time, which, within the terms of their theoretical account, was consistent with the operation of a faulty or invalid thematic framework. These issues concerning the representation of the temporal context of past events are addressed in a detailed single case study of a post-encephalitic patient in chapter 8. Following the suggestion of Hodges and McCarthy, particular emphasis is placed on the importance of retrieval frameworks for temporally-organised recall.

3.4 (ii) Memory and Psychological Time in amnesia

Many of the models of psychological time reviewed in chapter 2 were based on the assumption that awareness of interval duration is based upon memory for constituent events or contextual details surrounding events. It follows that time estimation may be deficient in cases of memory disorder, especially under retrospective conditions when the influence of attention is supposedly minimal. There are several means by which this may occur, depending on whether past events are being recalled or new events are being experienced. The consequences for putting past events into temporal context has been discussed in the preceding section. The next two sections will consider the relation between anterograde memory and time experience, starting with the monitoring of time in severe anterograde memory impairment. This section concludes with a brief discussion of the relevant phenomenological aspects of subjective time.

The capacity for intact or at least near normal procedural memory in amnesia is a defining feature of the syndrome (Parkin & Leng,1993). Therefore, to the extent that behavioural timing mechanisms were mediated by a procedural memory system (see chapter 2), one would expect that amnesia was compatible with preserved ability to regulate behaviour in time. In terms of non-complex actions such as locomotor skills this is the case although the situation is rather different for more complicated multiple subgoal tasks and will be addressed in the next section.

So far as the subjective awareness of time is concerned, it is recognised that even transitory cerebral insult such as TIAs or transient global amnesia can produce persistent disturbances of time estimation, possibly due to a residual working memory dysfunction (Wilson et al.,1980; Gallasi et al.,1986). More commonly prolonged disturbances of temporal awareness accompany persistent reduplicative or amnesic states. Few experimental studies have been reported but the sparse data are broadly consistent. Richards (1973) reported that time estimations (by the method of reproduction) from the amnesic HM were characterised by two different power functions, serving intervals shorter and longer than 20 seconds, a difference which the author suggested may reflect

limitations in HM's short-term memory. In fact, anterograde memory impairment is frequently associated with verbal underestimations of time (or over-estimations by the method of production) for periods greater than 30 seconds (Benton et al.,1964; Kinsbourne and Hicks,1990; Binofski & Block,1996), though other studies have shown consistent underestimation of time for periods longer than 10 seconds (Williams et al.,1989; Meyers & Levin,1992). These data suggest that time estimation in amnesia is accurate only within the variable limits of short-term or working memory capacity. Most clinical studies of this nature are atheoretical but it is interesting to note that Binofski and Block (1996) tentatively interpreted the slower subjective time of their frontal lobe tumour case in terms of a reduction in pulses generated by an internal pacemaker. [3]

Unfortunately, all of these clinically-based studies have some significant weaknesses. The fallacy of extrapolating judgments of short intervals in experimental studies to experienced "real world" time is well-recognised (Macleod & Roff,1936), and therefore Richards (1973) is unjustified in extrapolating from experienced intervals of 300 seconds to suggest that "one day is like 15 minutes; and one year is equivalent to 3 hours for HM." Furthermore, Richards (1973) and Kinsbourne and Hicks (1990) considered only mean time estimations which are insensitive to extreme over- and under-estimations of the same interval. Taking account of the potential variability in duration judgements, Nichelli et al., (1993) appeared to confirm that traumatic amnesics had problems estimating intervals that exceeded their short-term memory capabilities, although the time estimation tasks were not equivalent length for all patients. In contrast, Shaw and Aggelton (1994) standardised the task intervals and showed that post-encephalitic amnesics could verbally estimate durations of up to a minute in similar fashion to controls, ie. with equal accuracy.

Overall, the available data suggest that memory-impaired individuals experience duration fairly normally within the temporal span of their short-term or working memory. Beyond this immediate memory span, brain-injured subjects may be especially vulnerable to time

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distortions depending on the kind of cognitive dysfunction sustained. This issue is the subject of chapter 9, which reports detailed investigations of time estimation in a post-encephalitic patient.

Phenomenological aspects of temporal awareness in amnesia

There is an additional feature of temporal disturbance which is often overlooked in experimental studies but it concerns experiential aspect of severe memory disorder. These issues are not the main concern of the present thesis but, looking to the future, an appreciation of the phenomenology of the many facets of temporal disturbance will be a central part of a comprehensive understanding of psychological time. For the present, it is sufficient to recognise the importance of subjective experience, both at an individual level and in terms of the social implications.

Historically, time has typically been seen as a harbinger of change, even destruction, but in psychological terms time also permits appreciation of stability and continuity (Salmon,1985), key aspects which help to establish the concept of the Self and personal identity (Gergen,1971). The primacy of the Self was emphasised in his philosophical works by St Augustine (Freeman,1993) but in the Middle Ages concepts of time were centred on the present moment as the basis of experience. Compared to Mediaeval Man, who appear to have thought of themselves as existing *in* a given time, contemporary thinking recognises that the present is enriched by the temporal perspective of personal life histories. Recognising that people exist *through* time, and that separate experiences belong to the same individual is crucial to self-definition; as Locke stated: "as far as consciousness can be extended backwards to any past action, so far reaches the identity of that person...." (cited in Warnock,1987). Thus the appreciation of continuity of awareness over time, is the mainstay of self-identity. Sacks (1973) recounted several post-encephalitic cases whose 're-awakening' with L-dopa was accompanied by a profound sense of identity located back in the 1920's despite the fact that, if pressed, many could provide information which proved they were oriented to the then-present 1960s. Consistent with Edelman's (1990) suggestion that the basal ganglia provide a

basis for a sense of continuity through their role in control of movement, Sacks speculated that the disorder of akinesia is associated with an interruption in the temporal locus of self-identity.

Thus amnesic patients who have lost this sense of temporal awareness appear to be especially vulnerable to breakdown of the integrity of the Self. Hence amnesia offers, in Talland's (1965) phrase, "a world without continuity." Phenomenologically, one may speculate that this must invoke feelings of existing only in the present. Indeed, the notion of the present may be meaningless without an appreciation of temporal perspective, in which case it might seem like living the whole of one's existence in an instant. Fortunately, amnesia is never so dense that retrograde memory loss is complete or so global that all semantic as well as event information is lost from a life history. Yet there have been few studies exploring how individuals with severe memory loss reconstruct their sense of Self from fragmentary recollections, or how impoverished semantic information may be integrated into a life history.

Conceptually, the most relevant model here is the so-called narrative framework, by which memories are endowed with social meaning and value (Schank & Abelson,1995) and time itself derives meaning from the construction of narratives detailing the causal relations between events (Campbell,1996). Schank and Abelson (1995) suggested that the concept of Self also has an important social function mediated by communication of shared memories, each relevant to self-identity. Nevertheless, such recollections are prone to error, diary-keeping studies showing that memory for everyday events and activities is often less accurate than people expect, leading Fentress and Wickham (1992) to claim: "what is valuable about memory is not its capacity to provide an unshakeable foundation for knowledge, but, simply, its capacity to keep us afloat" (p.24). In order to work effectively therefore, everyday memory appears to require meaningful interpretation within a broader framework of self-knowledge, which includes representation of temporal context (Olton,1990).

This conceptual discussion is important because disorders of identity are common after severe brain injury (Prigatano, 1995) and, so far as social discourse depends on shared representations of event structures in time, it follows that some memory dysfunctions such as autobiographical memory impairment may directly cause reduced social functioning and, in severe cases, contribute to a breakdown in personal identity. This conceptual discussion is very much at the forefront of the chapter 10 as the post-encephalitic case reported therein presented with a breakdown of the continuity of self-identity which contributed to severe management problems for rehabilitation staff. The emphasis of the research throughout the thesis is on characterising deficits in subjective time awareness in terms of underlying cognitive processes. Nevertheless, it is equally important clinically to understand the personal experience of individual patients and to appreciate the implications of their disabilities in broader social and functional contexts.

3.4 (iii) Anterograde memory and Psychological Time: the role of context.

Whereas chapter 9 concerns the nature of time experience in the global disturbance of episodic memory that characterises the amnesic syndrome, chapter 10 which follows it addresses the particular relevance of contextual information for psychological time. A variety of approaches have been taken to studying contextual processes in memory, some of which suggest particular relevance for time estimation. For example, according to Block's (1978) contextual theory of psychological time memory-impaired subjects will have time estimation difficulties proportional to the magnitude of their memory impairment for context, rather than for events. In fact, remembered duration has been shown to be influenced by the extent of memory for contextual information, but this is not limited to memory for so-called temporal contextual material (Block,1990b). A major problem with these studies is that the distinction between an event and its context is not always clear. The more intimate the context with the target information the more difficult it is to discriminate between the two. Hence, in so far as context is peripheral to attention, deficits in effortful contextual processing inevitably also involve some processing of target information (Mayes et al.,1985). Perhaps the most useful framework

for exploring these issues was proposed by Baddeley (1982) who suggested two ways in which context may be encoded. He recognised that sometimes a context changes the way a stimulus or event is perceived and remembered. This kind of phenomenon can be seen in semantic priming for example, and Baddeley termed this *interactive* context. Alternatively, contextual information may be registered and stored along with the primary event but without changing the nature of the memory trace of the event itself (eg. environmental context).

Difficulties retrieving contextual information are common amongst many memory-impaired subjects. This is not to suggest that all memory deficits are primarily attributable to such a dysfunction; most of the evidence for the contextual-memory deficit theory of amnesia derives from diencephalic cases (Parkin & Leng, 1993) which often show particularly severe recall ability in the context of relatively good recognition memory (Kapur, 1993). Nevertheless the fact that memory dysfunction often encompasses deficits of contextual information processing suggests that clinical studies could help to elucidate the relation between memory, context and psychological time.

In particular, Baddeley's (1982) notion of interactive context is especially relevant because it places emphasis on processing carried out by the subject rather than on the properties of the stimulus material. Although generally recall paradigms tend to be more sensitive to active processes of recollection carried out by subjects, recognition memory tasks are equally sensitive to the effects of interactive context because, by definition, interactive context changes what is stored rather than operating at the retrieval phase. Thus recognition memory tasks have the advantage of being sensitive to interactive context while remaining relatively impervious to the effects of independent context. This is consistent with the proposal by Norman and Schacter (1996) that reinstantiation of contextual information is involved in the monitoring aspect of recognition every bit as much as it is in the retrieval function involved in recall.

Although amnesic patients may not derive the same benefits as non-amnesic subjects from interactive context (Mayes et al.,1992) in many cases recognition can be improved by provision of contextual details, though only to the extent that they interact with target material to change the nature of what is stored (Parkin,1993). The neurological underpinnings of these processes are unclear but there is a strong association of organisational and strategic aspects of mnemonic processing with frontal functioning (Moscovitch,1989; Shimamura et al.,1991). It so happens that the biomechanics of head injury (especially those caused by road traffic accidents) are such that victims tend to sustain anterior cerebral damage (Pang,1989; Troncoso & Gordon,1996). It follows that individuals surviving severe head injuries may be expected to have particular difficulties with the utilisation of contextual information for recognition as well as recall. The fact that recognition memory is frequently impaired after moderate to severe brain damage (Millis & Dijkers, 1993) appears to confirm this. These issues form the background to the study reported in chapter 10 which examines the contribution of memory for interactive and independent contextual information to retrospectively estimated duration.

3.4 (iv) Semantic memory and Psychological Time: telling the time.

In very general terms the notion of semantic memory storage includes words, concepts and numbers. Knowledge about time may therefore be considered a form of semantic memory, as the abstract concept of time has both linguistic and numerical representation. Brain injury can result in loss of conceptual knowledge about objects and words, which characterises the agnosic condition and semantic memory degradation respectively. In contrast to the comprehensive body of research into both agnosias and semantic memory disorders (Farah,1990; Chertkow et al.,1992; Rapp et al.,1993) there have been very few reports of a breakdown in the comprehension of time. The term 'time agnosia' appears to have been first used by Davidson (1941) to describe a constellation of time-related deficits in two head-injured cases which included poor time estimation and apparent ignorance as to the meaning of "verbal terms of time." Skull X-rays showed fractures of the temporo-occipital region, which one may speculate could have been associated with posterior temporal lobe damage (hence semantic memory impairment) and contre-coup

frontal dysfunction (giving rise to time estimation problems). More recently, Kartsounis and Crewes (1994) reported a patient who appeared temporarily unable to tell the time following a right hemisphere stroke. They used the term 'horologagnosia' to describe what they interpreted as a primary deficit in using time-based knowledge to tell the time.

Interestingly, clinical evidence suggests that temporal concepts and the ability to tell the time are typically preserved in many instances of memory impairment. This is evident in episodic memory disturbances such as retrograde amnesia (Kapur,1993) and transient global amnesia (Hodges,1991), and also in instances of 'semantic amnesia' (Grossi et al.,1988) and the various disorders that constitute the primary progressive aphasias (Hodges et al.,1994; Graham et al.,1997). Thus several sources of evidence suggest that time-related knowledge is relatively insensitive to breakdown in cerebral pathology. Furthermore, where semantic degradation is associated with temporal disturbance, as in Alzheimer's disease, the basis of this deficit is unclear. Nichelli et al. (1993) for example, suggested that the locus of temporal impairment could be due to semantic breakdown or the disruption of an internal timing mechanism.

Beyond the evidence, much of it anecdotal, that time-based knowledge is relatively robust very little is known about the nature of this temporal information, for example whether there is a separate category of temporal information or whether it is subsumed by numerical and verbal representations. Thus, in spite of the fact that many neuropsychological rehabilitation programmes rely, implicitly or otherwise, on familiarity with temporal concepts and the ability to tell the time (Cockburn,1996a), the cognitive processes involved in these skills remain poorly understood. In chapter 11 an analysis is undertaken of acquired impairments of the ability to tell the time ('clock-reading') in terms of the underlying cognitive components and the relation of this skill to other aspects of psychological time.

3.5 Executive Skills and Psychological Time:

Apart from a few social psychological studies which have a naturalistic perspective, all the evidence on subjective time estimation comes from experiments which take little account of the significance of time estimation in everyday life. This is especially true of the research on attention and memory which has been used to substantiate cognitive theories of psychological time (see chapter 2). In fact virtually all of it has been reported in psychonomic or experimental journals. Surprisingly little account has been taken of the importance of executive functions, although one would expect that these skills would be particularly significant with regard to time estimation in everyday life. The following review therefore addresses two hitherto neglected but important aspects of psychological time: the role of executive functions in time estimation per se, and the consequences of executive dysfunction for the temporal control of action.

3.5 (i) Time estimation as Cognitive estimation

It seems appropriate to begin a discussion of executive aspects of psychological time with the concept of problem solving, which is in many ways the essence of executive functioning. This is because time estimation is both a skill required for many aspects of general problems solving (see next section) and is a problem solving skill in itself. It is with regard to this latter sense that the present discussion is concerned.

One aspect of novel problem solving involves formulation of solutions for problems for which there is no readily available plan. This ability to make reasoned judgements about novel situations depends crucially on the integrity of higher-level cognitive processes such as planning, strategy-formation, anticipation and monitoring (Nauto,1971) and has been termed 'cognitive estimation' by Shallice & Evans,(1978). Like other kinds of problem solving, cognitive estimation may be conceived of as occurring by search within a "problem-space" within which there are both knowledge bases and a set of operators - information processes producing new states of knowledge (Newell & Simon,1972). From a clinical perspective Luria (1966) stressed the importance of not only the ability to

create a plan or hypothesis, but also a set of methods for plan implementation and "a series of operators leading to the correct answer." Effective problem solving therefore necessitates systems that traverse a problem space by the application of operators (Holyoak, 1995) though this process is vulnerable when faced with novel problems and may lead to increasing "proceduralisation" of action.

Difficulties in carrying out many such processes have been associated with damage to the prefrontal cerebral cortices (Milner,1982; Knight,1984). These deficiencies are evident on both psychological tests (Stuss & Benson, 1984; Kartsounis et al.,1991; Evyatar et al.,1990) and "real-world" functional tasks (Eslinger & Damasio,1985; Schalen et al.,1994). More specifically, poor ability to make cognitive estimations was originally reported by Shallice and Evans (1978) to be selectively impaired in patients with frontal lobe lesions.

The ability to make adequate temporal estimates is important on two accounts. Firstly, for assessing the validity of conventional verbal time estimation studies, and secondly because, it has been suggested that impaired cognitive estimation undermines the use of estimation processes in everyday life (Taylor,1990). This is supported by a study by Bruyer and Bontemps-Devogel (1979) who showed that sparing of temporal facts does not preclude deficits in manipulating temporal concepts to solve problems and regulate behaviour. Moreover, Ferguson and Martin (1983) reported that non-brain injured individuals had difficulties estimating how long ago events occurred. In fact they showed a typical centralising tendency to overestimate shorter intervals (exaggerate time since more recent events) and underestimate more distant events. Interestingly these subjects did not produce the more bizarre responses which characterise impaired cognitive estimation (see also Grafman et al.,1990) and therefore may not have had generalised cognitive estimation problems. performance. Alderman (1994) reported a dissociation between the poorer ability of frontal patients than non-frontals to estimate the durations of hypothetical activities, and equal performance in estimating real time intervals. Yet he only examined intervals of 60 seconds or less and it is likely that time

elapsed over longer intervals would be less accurately recalled and thus more susceptible to the cognitive estimation biases. Indeed, amongst both post-encephalitic and Korsakoff's amnesics, cognitive estimates performance was correlated with time estimation accuracy by Shaw and Aggleton (1994) who suggested that subjective duration is based on a memory-independent internal clock, sensitive to frontal dysfunction. Given the temporal basis of everyday problem-solving there would appear to be a need for more detailed study of temporal reasoning as a specific form of cognitive estimation. This is the subject of chapter 12.

3.5 (ii) Executive skills and Psychological Time: the temporal regulation of behaviour in functional context

As noted above, time estimation is both a problem solving skill in itself, insofar as it comprises a form of cognitive estimation, and is also an essential component of problem solving in complex tasks. Indeed, it is contended that the capacity for subjective time awareness exists because is it an adaptive skill: fundamentally it enables people to function better. This ability preceded the development of clocks and other icons of time in contemporary Society, and therefore one can surmise that it must be possible to temporally-regulate behaviour through action without recourse to clocks. This approach was also adopted by Rabbitt (1996) who argued that people are much better at regulating their behaviour according to 'living time' (ie. task-demands) than to clock time. He suggested, with something of a Gibsonian flavour to the argument, that temporal regulation is usually enforced by unfolding task structure (akin to temporal coherence), and that it is only "when we have to shift from one internally constrained behaviour sequence to another that we may have access to wider contexts of temporal orientation" (Rabbitt,1996, p.242.)

Although this argument may provide a plausible account of the manner in which people generally organise their behaviour in time, despite poor "instinctive" appreciation of clock time, it cannot be applied to certain clinical populations. In particular, persons

with frontal lobe brain damage are likely to have grave difficulties, not just in time estimation, but also in temporal regulation of their behaviour. Typically, deficits of this nature are viewed as a general problem in exercising executive control over behaviour, but, notwithstanding the operational constraints on manifestation of executive skills (Burgess,1997), they may well reflect a critical impairment in timing (see also Damasio et al.,1991).

Chapter 13 presents a single case study which examines the relationship between time-based processes of behavioural regulation and executive skills in the context of strategy application disorder (Shallice & Burgess,1991). A core feature of this disorder is an inability to interrupt on-going behaviour, a process which appears to be sensitive to frontal function (Maylor,1995; Glisky,1996). Although the realisation of intentions may well involve both hippocampal and anterior brain regions (Shallice,1996), access by the frontal lobes to some process of monitoring time appears to be a prerequisite to temporally-appropriate action (Cockburn,1995). Such time-based problems may be more extensive than global supervisory impairments (Shallice & Burgess,1991). For example, Cockburn (1996b) compared eighteen brain-injured patients with normal controls on two prospective memory tasks. The greatest disparity between the two groups was evident on the time-based task rather than stimulus-based task. These results highlight the importance of assessing temporal regulation of action in a functional context.

3.6 Rationale for the research methodology

The preceding sections have raised many issues that concern the psychological experience of time and some of the means by which psychological time is likely to be underpinned by component cognitive processes. In the chapters which follow these matters will be subject to more detailed investigation in a series of empirical studies. The chapters are grouped in three sections dealing with attention, memory and executive skills respectively. Previously it has been argued that psychological time must be appreciated as a complex adaptive acquisition which is necessary to goal-oriented

behaviour; thus the somewhat artificial tripartite division of the remaining chapters is undertaken only for ease of comprehension. The task of incorporating these dissected aspects of time experience into an integrated framework which recognises both cognitive and social perspectives will be left until the final chapter.

3.6 (i) The research design

In the following empirical chapters the principal method of investigation is the group study though some issues are explored through single case analysis. Although the merits of both of these approaches has been widely debated the combination of group studies and single-case investigations is increasingly being accepted as perhaps the most fruitful way to pursue clinical research (Burgess,1997).

From a purely theoretical perspective one would ideally use localised lesion cases, but this was not practicable. The experimental subjects were in fact mostly individuals who had sustained severe head injuries (and therefore fairly diffuse brain damage), although some of the single case investigations were undertaken with individuals with other aetiologies (principally stroke, anoxia and herpes simplex encephalitis). This composition and the fact that all were undergoing rehabilitation at the time of the study reflects the nature of the author's clinical work. The advantage of this approach, aside from ease of subject availability, is that the investigations were strongly motivated by a desire to understand more about the real life problems associated with disturbed temporal experience that are so rarely made explicit in rehabilitation.

There are also obvious limitations of this strategy. Clearly, the unavailability of unilateral/selectively lesioned subjects precludes investigation of the neurological underpinnings of the many different facets of psychological time (Godefroy et al.,1998). Yet because temporal experience is an area of cognition which has received very limited neuropsychological attention it was decided to pursue a series of iterative exploratory studies which would have the potential to be applied to specific lesioned cases in future

investigations. Given the current embryonic status of research in the field, the fact that there are few systematic clinical studies and no clinically-derived theoretical frameworks, the present approach was inevitably an exploratory venture concerned with several different issues regarding the nature of time experience. Future research will be able to refine key methodological and conceptual issues raised in the thesis.

A primary aim of the present research therefore was to develop a set of tasks which could be employed in future studies to examine some of the more promising empirical findings. For example, a core objective was to design a series of practical easily administered tests which would be sensitive to brain damage. Such tasks could then be undertaken with unilateral lesion groups which would allow more specific investigation of interesting theoretical issues raised by the present research (see final chapter). Another potential development lies with equating performance on the relatively short cognitive tasks developed in the thesis with temporal awareness over much longer time periods in everyday functional situations.

In order to provide an assessment of task performance which could be normatively evaluated and against which concurrent time estimation could be compared, standard neuropsychological measures were used as much as possible. This meant that many of the tasks employed would be already familiar to clinicians as tests used in clinical practice. At this point it is also worth clarifying what is meant by the notion of a 'task.' In contrast to standard neuropsychological assessments when a subject is engaged in one activity at a time, most time estimation studies are really dual task experiments. There is a primary task (usually the process of keeping track of time) and a secondary task (the activity one is engaged in during the interval which is to be timed). The validity of this distinction is an issue which will arise in several chapters and will be discussed in the final section. Throughout the research the secondary tasks were essentially familiar clinical tools which were employed according to novel procedures involving temporal judgements.

With regard to the design of the group studies, it was decided to compare the performances of two groups of severely head injured individuals with one another and with a 'normal' control group. In this way it is possible to distinguish between the specificity of a test for brain damage (ie. where control subjects outperform two similarly-performing groups of head injured subjects) and its sensitivity to severity of brain dysfunction (where the less severe head injured subjects performance is superior to the more severely disturbed group). The theoretical justification for this distinction is discussed in the next section.

In the research both the head injury groups comprise people who have technically sustained severe brain injures and so it is worth commenting at this stage on the clinical basis for making a distinction between them. Initially this decision reflected the differences in clinical presentation between members of the two groups. However, the subjects' neurological history confirmed that this clinical judgement was well-founded by revealing a significant disparity in the duration of post-traumatic amnesia exhibited by members of the two groups. Thus, not only did the mean length of PTA differ across groups but there was no overlap between them. Within this general design, slight differences occurred in the subject composition for each study and these are described in the relevant chapters.

One notable feature of the brain injured subjects employed in the present research is that they sustained very serious injuries and were very severely cognitively disturbed as a result. Consequently they represent only a minority of the brain injured population, but there are several advantages to studying this somewhat unrepresentative group. The investigation of subjects who in some sense represent 'extreme' cases is a useful means of establishing tasks and procedures which can later be refined for use with less severe cases. Appropriate case material for this approach can be either selectively lesioned cases or very severe generalised injuries. Theoretically too, one can develop hypotheses from the study of grossly disturbed patients, the generality of which can then be tested within less severe populations. Equally importantly, more of the severely brain injured

come to the attention of clinicians and therefore investigation in this population is more directly applicable to the working climate of brain injury services. Finally, a better understanding of temporal disturbance is really an initial step in trying to intervene to alleviate such problems, and since head injury is the most common kind of brain injury amongst most age groups and certainly the most debilitating economically, it seems appropriate to pursue this enterprise with this population.

3.6 (ii) The conceptual basis for inter-group differences

In any of the many experimental tasks reported in later chapters there are four possible outcomes. These are illustrated in figure 3.1 below where the y axis represents increasingly inaccurate timing and the x axis shows the control group then the two severely head injured groups in order of severity. First, as shown in plot (a) all subjects could perform time estimations with equal accuracy, in which case the task in question would be insensitive to brain damage; alternatively, the controls might show superior performance to both groups of head injured (b), suggesting a degree of task specificity for brain damage; there might be a linear relation between timing accuracy and severity of head injury, with the controls outperforming both head injury groups (c); finally, a task may differentiate only the most severe head injured subjects from the other groups (d).

In subsequent chapters the results will be evaluated in terms of their correspondence to these outcomes, though the overall interpretation of the data will be left until the final concluding chapter. At the heart of the interpretation though is the matter of whether the observations from head injured subjects are quantitatively different from those of the controls, or whether some or all brain injured subjects show a qualitative difference in their responses and, by implication, in their experience of time.

Certainly head injured subjects may be expected to show a decrement in performance as a result of a quantitative deficit in underlying processing resources. This possibility arises from an argument developed by Shallice (1988) that within a modular architecture the gross operation of subsystems can be measured by their resources. This means that

performance of a particular action or its constituent cognitive operations would reflect an impoverished version of normal mental processing. The resulting outcome might be observable in a number of ways. For example, a head injured person might complete a task at a much slower speed, or at a similar speed but with a greater number of errors than would be produced by a non head injured control.
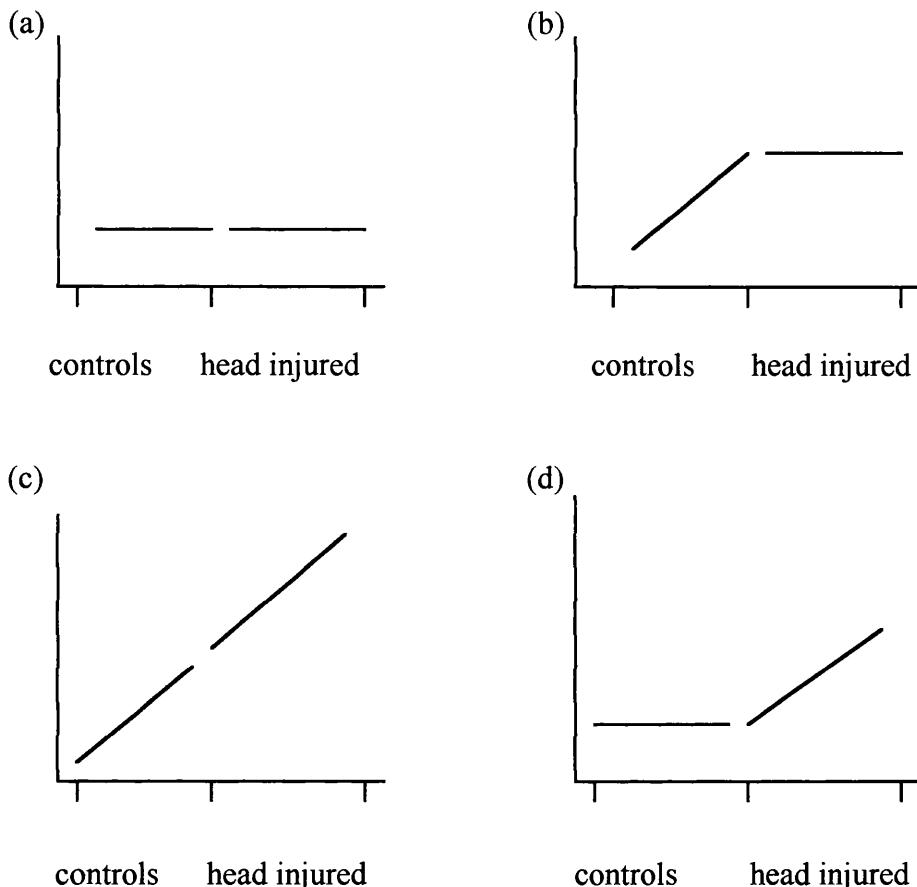
Figure 3.1 Possible experimental outcomes of time estimation studies

Alternatively, signs of processing decrements may be revealed in an inability to simultaneously undertake some corollary or incidental task. There is strong evidence that head injury predisposes individuals to these kind of problems which have been attributed to impairment of some sort of attentional (Foster et al.,1994) or working memory central

executive system (Van der Linden et al.,1992; Alderman,1996). In the context of many of the experimental studies to follow, prospective time estimation tasks which demand that a subject monitors the passage of time during an activity are therefore very much the kind of task which would be likely to show these difficulties. An inability to follow the passage of time during task execution should be reflected in reductions in any given measure of time estimation accuracy. If there is a linear relationship between processing resources and timing accuracy then this result would correspond to the outcome depicted in figure 3.1(c) above.

The arguments for quantitative differences between subject groups, expounded above, rest on the notion that the fundamental difference in cognitive abilities between persons who have and those who have not sustained a head injury is one of the *amounts* of processing resources. This is based on the assumption that damage to the brain reduces available cognitive processing capacity, a presumption which fits very well for specific tasks. However, there are clearly limits to this kind of argument and failure to acknowledge them would leave only an extreme 'mass action' (Lashley,1929) alternative, by which some global pool of 'processing resources' would be depleted proportional to severity of injury. This is clearly an unacceptable position and runs counter to the assumption of modularity in the architecture of cognition which characterises most current neuropsychological theorising. In fact, overall pattern of performance depends on the available processing resources only for a given procedure, and yet most tasks can be executed by more than one procedure or combination of subsystems.

Evidently there is a need to consider another mechanism for producing differences between subjects. This is in terms of the *nature*, rather than the amount, of cognitive processing engaged in a task. The argument here is that a damaged brain may result in disruption to a variety of cognitive systems, many of which may be functionally related in some reciprocal fashion and subject to all manner of post-injury reorganisation. Hence the resulting cognitive operations will be different in kind rather than simply in the

amount of resources available. To argue otherwise requires a considerable leap of faith in assuming that the outcome of these processes will leave the cognitive system essentially the same, minus one or two bits here and there.

On this basis there are grounds for considering that at least some aspect of the complex arrangement of subsystems may be operating in non-normal fashion after brain injury. An appreciation of how this may occur is equally as compatible with a modular view of cognition as is the argument for quantitative resource loss developed above. The two are not contradictory. If it is assumed that task performance requires the use of a procedure and that each procedure requiring a specific subsystem makes qualitatively equivalent demands on its resources (Shallice,1988) then the usual outcome for a task performed by a lesioned system (in this case a head injured brain) would be a quantitative decrement in processing resources for that task. On this basis there would be no grounds for predicting a qualitative difference between subject groups, and the outcome would still correspond to that illustrated in figure 3.1c. However, it is also reasonable to assume that the severity of a fairly generalised cerebral insult like a traumatic head injury is related in some rather gross fashion to the extent to which cognitive subsystems are damaged. Theoretically this means that there is an increased likelihood of certain systems being damaged, or damaged to a greater degree with the more severe head injury. Indeed this is reflected in the nature of the two clinical groups used in the research, as most of the severe head injured had recovered sufficiently to live with their families at the time of testing, in contrast to the very severe head injured for many of whom this would never be possible. As regards their performance on time estimation tasks, then as a consequence of the greater involvement of cognitive systems amongst the very severely head injured subjects, one would predict that their performance may differ qualitatively from those persons with less extensive brain damage.

In terms of the analysis of group differences, data from most of the subsequent empirical chapters are subject to two orthogonal statistical comparisons. Results are analysed first for potential differences between controls and head-injured subjects. This type of

analysis should reveal those tasks which are insensitive to brain injury (figure 3.1a) and those tasks in which poor performance is specific to brain damage (figure 3.1b). The second statistical analysis compares the performance of the two head injured groups. This will demonstrate where tasks are sensitive to severity of brain injury (figures 3.1c and 3.1d). The analyses are statistically independent but considered together they will determine the general pattern of results for any given experimental procedure. For example, there may be no overall difference between head injured subjects and controls on the first analysis, but a clear disparity between the two head injury groups on the second analysis. This corresponds to the outcome depicted in figure 3.1d and raises the possibility of task performance being undermined by non-normal cognitive operations affecting the more extreme cases. Alternatively, if there is a linear trend in performance as the resource-loss argument would predict there should be differences between the controls and head injured and between the two head injury groups (figure 3.1c). Examples of these two processes in action will be given later in the empirical section of the thesis.

SECTION TWO

Attention and the Experience of Duration

Chapter 4

Attention and Psychological Time:

The role of temporal order

4.1 Introduction

An overview of attentional accounts of psychological time was provided in chapter 2. From this it was apparent that virtually all attention theories incorporate the hypothetical distinction between temporal and non-temporal information, despite the ambiguous nature of this dichotomy. Although attentional models do not endow non-temporal information with any special significance with regard to time experience (Block,1992), this leaves open the issue of whether temporal information of any kind contributes to duration experience in the same way. The present chapter, and chapters 5 and 6 which follow, all seek to address this issue.

Perhaps the most obvious form of temporal context is stimulus sequence or event order, and yet little investigation has been undertaken into the relation between order and duration. Consequently, in current models of psychological time the status of the temporal order of events as a basis for subjective duration is equivocal. Cognitive accounts tend to treat order and duration separately (Block,1990a) whereas internal clock models incorporate an accumulator in which event order is registered and where the correspondence of event registration with internally generated pulses gives rise to an appreciation of duration (Nichelli,1996). However, classical internal clock theories propose that event order is encoded automatically and thus one should not expect a significant attentional contribution to registration of event sequence. In contrast, cognitive theorists (Michon,1978; Jackson,1990) have emphasised the importance of effortful processing of temporal information which is consistent with current limited capacity notions of attention (see chapter 2). The issue is of particular interest in relation

to head injured persons because they are especially prone to primary disturbances of attention (Manly & Robertson,1997).

One reason why the relation between order and duration has been neglected may be because research into temporal order has largely been undertaken by memory theorists. Most of the temporal order paradigms are therefore memory tasks sensitive to recall of event sequence. As discussed in the previous chapter in section 3.3 (i), temporal order tasks such as recency memory tests are sensitive to both attention and memory deficits. However, in a prospective time estimation task the role of memory for event order is minimised as it requires concurrent monitoring of duration. It should be possible therefore to explore the role of temporal order information, while minimising the general memory load by making the task more sensitive to attention.

The following investigation was therefore undertaken to explore the relation between time experience and event order in the form of recency information. The tasks employed were recency memory tasks which means that attention to event order is not tested directly but inferred from recall performance. Nevertheless, as it is attention to time which is the critical aspect of the task this is not an insurmountable problem. There may be other reasons why cognitively impaired subjects may have difficulties with the task but further consideration of these issues is left until the discussion below.

4.2 Method

Material

As there is some evidence for material-specific hemispheric specialisation in the processing of recency items (Milner et al.,1991) two sets of recency memory stimuli were devised. An abstract verbal set comprised 56 white inspection cards (3" x 5") and 48 pink response cards (the latter necessitating 35 recency and 13 recognition judgements). Using normative data from Paivio et al., (1968) it was established that there were no significant differences in word frequency and concreteness between the words used on

the inspection cards and those employed as targets or foils on the recognition cards. The first eight cards were white inspection cards, thereafter inspection and response cards were alternated. Response cards contained two abstract words arranged across the card (eg. Love - Custom). The 35 recency cards contained stimuli which had both previously been presented on inspection cards. Four levels of recency were used, ie. the stimulus words first appeared either 4, 8, 16, or 32 cards previously, which yielded six possible comparisons (4 vs 8, 4 vs. 16, 4 vs. 32, 8 vs. 16, 8 vs. 32, 16 vs. 32). Thus the number of words separating the initial presentation of a stimulus word from its re-appearance on a response cards was either 4, 8, 12, 16, 24 or 28 items. The 13 recognition cards contained only one word which had previously been presented, these were randomly interspersed throughout the pack. The target word on the recognition card had been initially presented either 4, 8, 16, or 24 cards previously.

A second deck of stimulus cards was specially devised consisting of abstract designs, loosely-based on Vanderplas and Garvin (1959). This pack of 67 cards comprised 37 inspection cards and 30 response cards (necessitating 20 recency and 10 recognition judgements). Four levels of recency were utilised (2, 4, 8 and 16 cards distant) again yielding six intervals of recency (ie. 2 vs.4: three cards; 2 vs. 8: four cards; 2 vs. 16: four cards; 4 vs. 8: three cards; 4 vs.16: three cards; 8 vs. 16: three cards). Target words on the recognition cards had been presented either 2, 8 or 16 cards previously (in three, four and three instances respectively). A practice deck of thirty cards utilising high frequency (A/AA) concrete words was also compiled, using the same principles described above for the stimulus sets.

Subjects

Three groups of subjects were employed in this study, as in most of the empirical investigations reported in the following chapters. In order to satisfy the minimum generally accepted criterion for statistical sensitivity (70%) at the .05 level, it was calculated that at least twelve subjects would be needed in each group (Kraemer & Thiemann,1987). Two groups of head-injured patients were recruited from post-acute

neurological/ neuropsychological rehabilitation facilities. As discussed in chapter 3 (section 3.6) they were distinguished in terms of injury severity and by the nature of their rehabilitation. Although both groups comprised individuals who had sustained very significant cerebral injuries, one group was receiving community-based, mostly cognitive, rehabilitation (see BPS working party report, 1989; Chamberlain et al.,1995) and one group comprised patients with prolonged confusion and associated behavioural problems amenable to a specialist unit approach (Wood,1990). All subjects in both groups had suffered traumatic head injuries involving an external impact (as opposed to a primary brain haemorrhage, for example). Most subjects had sustained closed head injuries involving blunt impact, usually caused by acceleration forces, as commonly occurs in a road traffic accident. Some subjects sustained skull fractures, a few had required surgical intervention, usually to relieve focal sequelae such as a haematoma, but sometimes to relieve severe intracranial pressure.

Although there is no direct correspondence between neuropsychological deficits and magnitude of brain damage (Wilson,1994), on the basis that standard measures of injury severity are associated with global cognitive outcome (Jennet 1976; Thomsen,1984; Ponsford,1995), it seems reasonable to assume that injury severity would be related to the likelihood of post-traumatic temporal disturbance. Imaging data on the experimental subjects were examined where available, although this was usually in the form of an early CT, which is less sensitive than MRI to the white matter lesions one would expect in traumatic brain injury. As structural imaging techniques may miss functional lesions (Newton et al.,1992; Oder et al.,1996), this is an incomplete and unreliable source of information about injury severity, and therefore another criterion is needed.

One obvious candidate criterion is the period of post-traumatic loss of consciousness which is often assessed clinically using the Glasgow Coma Scale (GCS). Unfortunately, it was not feasible to evaluate the head-injured groups in terms of a GCS index due mainly to inadequate information in clinical records. Where available the data were noted for completeness. However, although a reasonably good predictor of global

outcome (Alexandre et al.,1983) total GCS scores are an unreliable indicator of injury severity (Jennet,1979). For instance, the timing of GCS assessments is known to be crucial to their interpretation but is often not recorded.

Instead, duration of post-traumatic amnesia (PTA), defined from date of injury (Russell,1932), was used as this is recognised as a useful alternative index of injury severity (Wilson et al.,1993). For subjects participating in the present research this was assessed retrospectively, though not always by the present investigator as some subjects were studied several years post-injury. Retrospective assessment inevitably has its problems (Forrester et al.,1994) but its validity is accepted (McMillan et al.,1996) and it is adequately reliable at the most severe end of the spectrum (King et al.,1997). However, this method of classifying patients did pose one problem which arose due to the very serious nature of the brain damage incurred in the clinical subjects and the insufficient sensitivity of classification schemes at the extreme end of the injury spectrum. Thus according to a standard taxonomy such as proposed by Jennett and Teasdale (1981), injuries are classified as severe if PTA lasts between one and seven days, very severe up to 4 weeks, and extremely severe thereafter. This division is inadequate for present purposes however, as both brain injury groups would be classified as extremely severe on this measure alone, despite clinical differences between them. Therefore it is necessary to depart from convention and adopt a working classification for simplicity by which the two groups of extremely severely injured subjects will be termed 'Severe' and 'Very severe' depending on whether they sustained a period of post-traumatic amnesia or prolonged confusional state which persisted for more than 12 weeks. This re-labelling of the groups is simply a pragmatic alternative to designating them "extremely severe" and "even more extremely severe." Obviously, undertaking the research with such grossly impaired individuals has ramifications for understanding temporal disturbances associated with head injury of any kind, but discussion of these matters can be left until the final chapter.

The kind of control subjects recruited is also of importance in research involving head injured participants. Ideally control subjects should be prone to similar risk factors and differ only by not having sustained a head injury (McMillan & Glucksman,1987). Therefore for the studies reported in this chapter and all subsequent ones which rely on the same research design, the control group comprised age-matched orthopaedic patients recruited from an acute hospital ward. Some subjects were assessed at the bedside in hospital, others were assessed at a later date as out-patients. This mixed inpatient/outpatient testing paralleled the manner in which many of the head-injured subjects were assessed. There are good reasons for selecting another clinical population to compare with the brain-injured groups, not least because, compared to healthy controls, orthopaedic participants could be considered vulnerable to the non-specific aspects of hospitalisation such as boredom and routine which might affect their experience of the passing of time.

It is important to establish intellectual parity amongst control and clinical groups as far as possible, as several studies have reported an association of head injuries in the lower social class groups (Rimel et al.,1981) and amongst those with fewer years of formal education (Kraus,1978). In practice this meant trying to match the controls and head-injured groups in terms of premorbid IQ as well as equating the two head injury groups on current intellectual level. Subjects were excluded if they had a diagnosis of psychiatric disorder following or pre-dating their head injury, if they had sustained a previous head injury of at least mild degree, or if they had a history of developmental learning disabilities. Some subjects were included throughout the study who had a history of alcohol consumption above recommended guidelines (to avoid acquiring a misrepresentative sample of head injuries) but those with current alcoholic difficulties or with a suspected Wernicke-Kosakoff's disorder (see Caine et al.,1997) were excluded.

In the present study two groups of head-injured patients were recruited, designated as severely injured (N=14) and very severely injured (N=12). A group of age-matched orthopaedic control subjects (N=11) was also enrolled. The 'severely head-injured'

group was matched with the control group on the NART-R index of premorbid functioning. Unfortunately, the presence of acquired reading problems in many of the 'very severe' group precluded valid administration of the NART with this second group of head injured subjects (see also Rand et al.,1990). However, the two head-injured groups were themselves matched in terms of current intellectual level on a short WAIS-R, and distinguished from one another in terms of length of PTA - indistinguishable in the extreme from prolonged confusion, (ie. means of 8 weeks vs. 39 weeks, $t = 6.13$ (24) $p < .001$) and length of time post injury (means of 12 months vs. 60 months, $t = 3.20$ (24) $p < .01$). This descriptive information is summarised in table 4.1.

	Orthopaedic Controls	Severely head injured	Very severely head injured
Age (yrs.months)	43.3 (16.9)	38.2 (14.6)	40.3 (12.0)
Sex (M:F)	6:5	11:3	12:0
Time post injury (months)	-	12.2 (11.6)	58.3 (49.9)
PTA (weeks)	-	8.7 (9.2)	39.5 (6.4)
NART-IQ	108.6 (7.6)	101.2 (7.1)	-
WAIS-R FSIQ	-	84.5 (10.7)	81.4 (12.7)

Table 4.1: Summary of background and clinical information on all subjects in recency memory study (mean values and standard deviations)

Procedure

Subjects were first presented with the practice deck of concrete word cards which were used to explain the task requirements. The instructions were slightly modified from those described by Milner et al., (1991). Subjects were administered an unlimited number of trial runs with the practice deck until they obtained at least three consecutive correct recency judgements. The abstract word task was then introduced, with subjects

being given the same instructions, in addition to which subjects were also told: " *at the end of the task, when you have finished, I will ask you how long you think it took you to complete the task. So you will need to keep track of the time as you go through it.*" The abstract word recency task was always administered before the abstract visual task, as it was deemed easier for subjects to comprehend the requirements of the latter, if they had previously completed the verbal equivalent. As these tasks were undertaken as part of a more extensive neuropsychological assessment, it was possible to ensure that an interval of at least twenty minutes separated administration of the two recency memory tests.

Calculating time estimation distortion

Following the approach in psychophysics of using logarithmic functions to represent subjective judgements (Luce & Krumhansl,1988), a simple formula was used in the present study (and throughout the following chapters) to reflect the magnitude of time estimation bias. Initially distortion in subjective time estimation was calculated as a ratio of estimated time ψ to clock time t:

$$\text{Subjective time distortion} = \psi \, / \, t$$

This formula was used to calculate whether one subject group showed a tendency to under-estimation ($\psi/t < 1.0$) or over-estimation ($\psi/t > 1.0$) of duration relative to another sample group. However, although this method takes account of inter-subject differences in task duration, it leaves open the possibility that skill in time estimation varies and is skewed upwards (because there is a bottom zero but no upper limit). Therefore it was decided also to calculate an adjusted time estimation accuracy score theta (θ) by modifying the ratios accordingly:

$$\text{If } \psi > t \text{ then } \theta = \psi \, / \, t - 1$$

$$\text{If } t > \psi \text{ then } \theta = t \, / \, \psi - 1$$

This allows calculation of the propensity to under- or over-estimate duration relative to clock time, in other words, accuracy of subjective timing. In the present chapter and later empirical investigations most of the results will be reported in the form of time estimation accuracy values for θ, such that values approaching zero reflect greater accuracy. Some chapters will also report subjective time distortion values (abbreviated to ψ) where it may be relevant to comment upon a consistent tendency to over or underestimate an interval.

4.3 Results

In the present results, and those from subsequent chapters, exploratory data analysis did not justify rejection of the assumption of normality in the data. Therefore parametric statistics will be used unless the data strongly suggest otherwise. In ambiguous cases it is appropriate that both forms of analysis are undertaken, but only the parametric results will be reported unless the non-parametric analysis yields very different results or there are grounds to adopt the more conservative non-parametric criteria. The generally accepted significance level of .05 was adopted for all comparisons. Given the exploratory nature of the investigations undertaken, non-significant results (ie. $p > .05$) will only be reported where they are consistent with a general trend which has been demonstrated to be statistically significant. In the majority of instances the variability of the time estimations produced by experimental subjects far exceeds that of the controls, violating the homogeneity of variance assumption required by ANOVA. In such cases this is apparent in the results tables and figures, and such data are subject to logarithmic transformation for the purposes of statistical analysis. Log. transformation is a particularly useful method for normalising positively skewed distributions which commonly occurs when the data are in the form of a time scale (Winer,1971). The experimental results will be discussed in two sections, in terms of recency memory performance and time estimation respectively.

Recency memory

Table 4.2 shows the subjects' scores separately for recognition and recency components of both verbal and visual memory tasks. As discussed in section 3.6, two orthogonal statistical analyses were undertaken. First, the scores of the control group were compared with the average of the two head injury groups in order to examine the relevance of brain injury to task performance. Second, the performance of the two groups of head injured subjects was compared to explore the effect of injury severity.

	Orthopaedic Controls	Severely head injured	Very severely head injured
Verbal recognition (max. 13)	12.00 (0.76)	10.06 (2.57)	8.75 (3.04)
Verbal recency (max. 35)	22.82 (4.21)	15.81 (2.57)	16.92 (3.26)
Visual recognition (max. 10)	8.36 (1.12)	7.62 (1.45)	7.54 (1.21)
Visual recency (max. 20)	8.90 (3.11)	9.88 (3.46)	7.18 (4.53)

Table 4.2 Results of verbal and visual recency tasks for all subjects
(means and standard deviations)

With regard to the recognition memory component of the verbal memory task , Analysis of Variance (ANOVA) demonstrated a significant difference between the scores of the control group and the head injured subjects ($F = 8.34$ $(1,37)$ $p < .01$), suggesting that verbal recognition judgements were poorer after brain injury. However, there was no significant difference between the scores obtained by the two head injury groups; thus suggesting that the presence of a brain injury but not the severity of injury was associated

with poorer recognition memory performance. In terms of the recency memory scores on the same task, there was an even greater difference between the controls and the head injured subjects than was evident in recognition memory judgements ($F =16.75$, $(1,37)$ $p < .001$). In contrast, the two head injury groups again performed similarly, there was no significant difference in their verbal recency scores, both performing at chance level on this component of the task (see table 4.2).

As for the abstract designs test, there were no significant differences between the groups on the recognition memory component although the controls showed a tendency to obtain higher recognition memory scores than head injured subjects ($p = .10$), consistent with the pattern of performance on the verbal memory task. Rather disappointingly all subjects seemed to be showing a floor effect on the recency aspect of the visual memory task (see table 4.2) and therefore further analyses were not undertaken.

Time estimation

The accuracy of prospective time estimations of the three subject groups for both tasks is shown in table 4.3. First of all, a visual inspection of mean and median scores suggests that the duration of the memory tasks, especially the verbal task, was experienced rather differently for each group, with the controls tending to show the most accurate time estimations. Because of the uneven variances in the results, the data were log. transformed and then subject to parametric ANOVA. This showed that there a slight tendency for the controls to judge the visual memory task duration more accurately than the head injured subjects ($p = .25$), a disparity between the groups which was statistically significant for the verbal task ($F = 5.22$, $(1,34)$ $p < .05$). Thus, the control group not only produced superior verbal recognition memory and verbal recency scores than the head injured subjects, they also showed more accurate estimation of task duration (see figure 4.1 overleaf). There was no difference in estimated duration between the two head injury groups.

There was no significant relation between recognition memory and recency memory scores. Furthermore, detailed examination of the relation between estimated duration and memory was prevented by the floor effect apparent in the performances of the clinical subjects on recency components of both tasks. Notwithstanding this, there was some suggestion that higher recency scores were associated with improved timing, in that accuracy of estimated time and recency memory scores were negatively correlated on the visual memory task for the very severely injured group ($r = -0.69, p < .02$). Similarly, on the verbal recency task there were signs (though not statistically significant) that timing was related to recency memory scores for the controls ($r = -0.52, p = .10$) and the severely head-injured group ($rho = -0.48, p = .60$). The estimates of task duration produced by the severe head injury group for both visual and verbal memory tasks were significantly correlated ($r = 0.88, p < .001$).

	Orthopaedic controls	Severely head injured	Very severely head injured
Verbal recency task			
completion time (sec)	252.2 (101)	282.7 (164)	330.9 (133)
mean θ (SD.)	0.43 (0.48)	1.40 (1.87)	1.32 (1.30)
median θ	0.26	0.89	1.08
95% CI's	0.11 - 0.75	0.32 - 2.28	0.44 - 2.20
Visual recency task			
completion time (sec)	212.0 (71.2)	228.3 (100)	353.3 (235)
mean θ (SD.)	0.33 (0.25)	0.81 (1.62)	0.91 (0.87)
median θ	0.24	0.39	0.64
95% CI's	0.16 - 0.50	0.00 - 1.75	0.28 - 1.53

Table 4.3 Accuracy of prospective duration judgements (θ)

Verbal recency
Time estimation accuracy
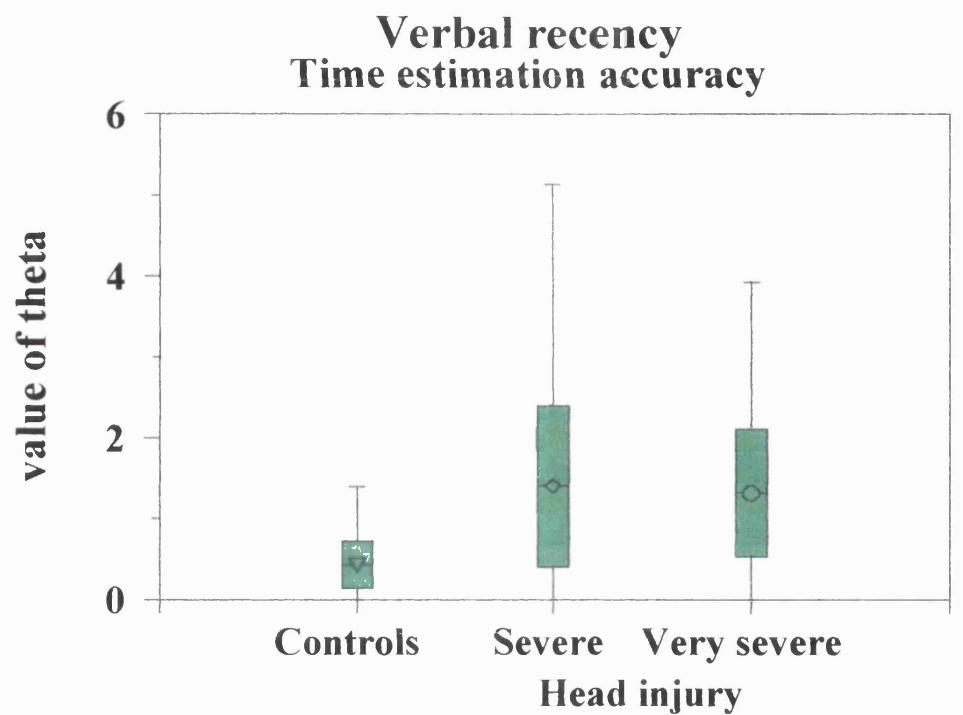
Figure 4.1 Accuracy of estimated duration of verbal recency memory task
(means, +/- 2 standard errors, +/- 2 standard deviations) across subject groups

4.4 Discussion

The results demonstrate that non brain injured control subjects were able to judge the duration of the verbal memory task more accurately than were head injured subjects, and they also showed a trend towards more accurate timing of the visual memory task. However, the standard deviations of the head injury data are very large in comparison with the observations of the control sample. Thus, despite the clinical differences between the two head injury groups, there was no difference between them in time estimation accuracy. In view of the floor effect on recency memory shown by both groups of head injured subjects, the absence of a difference in timing accuracy may have been due to the failure of the memory tasks to differentiate between the groups. The presence of a brain injury amongst the subjects was also related to poorer recognition memory and recency memory scores on the verbal memory task. Again, the two head

injury groups performed similarly to one another. These data therefore reveal an association between severe brain damage and both poor timing and poor performance on the memory component of the tasks.

This may seem contrary to an attentional account of psychological time which proposes an inverse relationship between task performance and timing accuracy, such that subjects who perform poorest on the memory task should show the most accurate timing. However, this postulate comes from studies with healthy subjects, whereas for head injured samples an inverse relation between timing and task performance may not hold. Decrements in attention which are most likely to be afflicting the head injured subjects (see section 4.1 above) could plausibly be responsible for both the poorer memory test scores and the relatively inaccurate timing. Interpreted in this manner, deficits in attention are likely to have compromised attention to time and to task.

Recency memory tasks were selected for this study as a means of investigating the relation between event order (in this case recency information) and estimated duration. Unfortunately the tasks used in this investigation did not elicit a selective impairment in temporal order and therefore it was not possible to examine this further. The correlations obtained between recency measures and timing may simply reflect an artefact of test design, in that there were roughly twice as many recency items as recognition items which made it easier to derive a significant correlation between timing accuracy and the recency memory scores. As they stand the results offer no real support for the contention that temporal order information has any privileged relation to experienced duration as internal clock models tend to imply, but acknowledged deficiencies in the experimental design precluded proper testing of this hypothesis. Speculatively one might conclude that temporal order as a form of temporal context is independent of processes mediating experienced duration.

Chapter 5

Attention and Psychological Time:
The relevance of temporal coherence

5.1 Introduction

Following on from the previous chapter which explored the role of temporal order in duration, the present chapter takes this matter a stage further by examining the notion of the temporal structure inherent in an interval. As discussed in chapter 2, the idea that the internal temporal organisation of events could offer cues to interval duration is attributable to social psychological and 'ecological' traditions within psychology. In chapter 3 it was argued that temporal order in narrative form (temporal coherence) may function as a general organising scheme for information processing such that intervals of different temporal structure would be experienced as different in length. According to the Kintsch and van Dijk (1978) model of text comprehension this would reflect different degrees of overlap between macropropositions within a working memory buffer (see chapter 2). It seems plausible that any attenuation of attention or working memory capacity is likely to limit on-line text processing such that differences in temporal coherence will result in different amounts of information being processed. In terms of attentional accounts of psychological time, the more processing resources that are allocated to the narrative, the less accurate should be the resulting time estimation.

Certainly, poor recall of narrative information is common after severe brain injury, which might lead to expectations of a concomitant reduction in timing accuracy. However, time experience for periods up to one minute appears to depend on short-term retention and rehearsal processes (Richards,1973; Williams et al.1989; Kinsbourne & Hicks,1990; Nichelli et al.,1993) and may be experienced by memory-impaired subjects fairly accurately. Thus one might expect the influence of temporal coherence as an organising framework for information processing to be evident only for intervals which exceed working memory capacity.

The present investigation was undertaken to explore the relation between temporal structure, information processing and the experience of duration. In order to distinguish between the temporal coherence of events in an interval and memory for the constituent events (which may itself be affected by intrinsic temporality), a prospective time estimation paradigm was employed. This permits the effects of interval content on memory to be assessed separately from the effects of content on experienced duration.

5.2 Method

Material

Two versions of an auditory-verbal recall task from the Adult Memory and Information Processing Battery (AMIPB, Coughlan & Hollows,1985) were administered in the study. Although presented as parallel forms of the same task, normative data suggest that (at least for the 46-75 age group) one story, "Peter Williams" is slightly more difficult than the other, "Angela Harper." Temporal coherence of the passages was analysed in terms of the temporal congruity of each statement, ie. the degree to which succeeding statements reflected the order of actions to which they referred. The stories are already divided into scorable segments or tokens, each of which, for the present analysis was designated as *congruent* if the token referred to an action which had immediately followed the act referred by the preceding token. The token was designated as *incongruent* if its referent act did not follow directly from the previous statement. An comparative analysis of the two passages (abbreviated to AH and PW) in this way reveals contrasting temporal properties such that the AH narrative is approximately 80% temporally congruent, whereas the PW story exhibits only about 20% temporal congruity.

Subjects

As in the previous chapter two groups of closed head-injured subjects were employed in this study. They were designated as severe (N=15) and very severe (N=14) in accordance with the PTA cut-off of 12 weeks discussed in chapter 4. The subjects were matched for age and present intellectual status on the WAIS-R and constituted approximately the

same sample who were employed in the previous investigation. Although both groups comprised individuals who had sustained very severe brain injuries, they were differentiated in terms of clinical presentation and injury severity as defined by length of PTA. Thus the more severe of the two groups was associated with prolonged post-traumatic confusion and behavioural problems. This latter group could not undertake the NART reliably and were therefore matched on current WAIS-R performance only. The inclusion of orthopaedic controls is particularly important as some research suggests that accident victims are likely to suffer task-irrelevant concerns which may impede working memory (Richardson & Snape,1984). The clinical details of the subject groups are summarised in table 5.1 below.

	Orthopaedic Controls	Severely head injured	Very severely head injured
Age (yrs.months)	42.1 (15.6)	38.3 (14.4)	37.3 (10.4)
Sex (M:F)	8:7	13:2	14:0
Months post injury	-	9.1 (7.6)	67.6 (58.1) *
PTA (weeks)	-	7.0 (7.2)	42.8 (4.5) **
NART-IQ	107.5 (9.8)	102.4 (8.2)	-
WAIS-R FSIQ	-	83.6 (9.9)	75.4 (9.1)

Table 5.1 Summary of clinical characteristics of subjects (means and SD.s)

$* p < 0.01, ** p < 0.001$

Procedure

The subjects were adminstered the Peter Williams and Angela Harper stories from the AMIPB, as part of a more comprehensive neuropsychological assessment. The only departure from the standard administration instructions was that subjects were told that

they would be asked at the end of the story, how long it had taken to read the passage out to them. Thus the emphasis was on prospective time estimation, assessing how time was experienced during the task. Participants were reminded that they would also be asked to recall as many details from the passage that they could remember. In order to facilitate performance among the more severely impaired subjects, they were told that it was not necessary that they try to recall information in the order in which it was presented. The stories were administered at least thirty minutes apart, and in quasi-random order across subjects. The subject always provided a time estimate before recalling information from the narratives.

5.3 Results

The clinical characteristics of the three subject groups are summarised in table 5.1. There were no significant differences in age between the groups. The controls and the severely head injured group were equivalent in premorbid intellectual ability, as indicated by the re-standardised NART. In addition, the two head injured samples were functioning within the same range on current WAIS-R IQ. As reported in previous chapters, although all head-injured subjects sustained very severe injuries, two groups are discernible in terms of the magnitude of PTA ($t = 9.21$ (df,28) $p < .001$) with the more severely disturbed group also being tested significantly later after their injury ($t = 3.34$ (df,28) $p < .01$).

5.3 (i) Memory performance

The recall scores for high and low temporal coherence stories are reported in table 5.2 below. The control group mean score was at the 50th percentile for the AH story and within the 25-50th percentile range for the PW story, thus indicating that the controls were performing within the normal range on these tasks. All the inferential analyses which follow are parametric and two-tailed unless otherwise indicated. The orthopaedic control subjects obtained significantly higher immediate recall scores than the brain injured subjects on both the AH story (F = 20.52 (1,36) $p < .001$) and the PW passage (F

= 25.41 (1,36) $p < .001$). Likewise, the severe head injury group performed notably better than the very severe group on the AH narrative ($F = 6.81$ (1,23) $p < .05$) and the PW story ($F = 4.53$ (1,23) $p < .05$). Interestingly, significantly more information was recalled from the AH story than the PW version by both controls ($F = 10.17$ (1,13) $p < .01$) and the severe head injury group ($F = 18.67$ (1,14) $p < .001$), while the very severe group showed a tendency ($p < .2$) to the same effect.

	Orthopaedic Controls	Severely head injured	Very severely head injured
AH story			
Immediate recall (max. = 56)	33.4 (6.0)	22.1 (10.9)	11.8 (9.7)
Percentile rank	50 %	15 %	< 2 %
PW Story			
Immediate recall (max. = 60)	26.1 (8.8)	14.2 (8.1)	8.2 (5.7)
Percentile rank	25-50 %	< 5 %	< 2 %

Table 5.2. Immediate recall scores for each auditory-verbal narrative

5.3 (ii) Experienced duration

The accuracy of subjects' judgements of task duration is summarised in table 5.3 and figures 5.1 and 5.2 below. The skew in the results is clearly evident and for this reason the data were log. transformed prior to parametric analysis. When the two head injury samples were combined ANOVA demonstrated that control subjects were significantly more accurate in estimating the duration of the AH story ($F = 5.39$ (1,38) $p < .05$) and the PW passage ($F = 5.24$ (1,38) $p < .05$). However, in this case the severe head injury group

are performing similarly to the controls but markedly better than the very severe injury group for both AH ($F = 15.86$ (1,24) $p < .001$) and PW narratives ($F = 10.97$ (1,24) $p < .01$). The effect of temporal coherence was not significant in relation to subjects' estimates of task duration.

	Orthopaedic Controls	Severely head Injured	Very severely head injured
AH Story			
mean θ (SD).	0.70 (0.79)	0.72 (0.87)	4.01 (1.02)
medianθ	0.81	0.94	3.64
95% CI	0.20 - 1.20	0.09 - 1.34	1.69 - 6.33
PW Story			
mean θ (SD.)	0.81 (0.94)	0.94 (1.21)	3.64 (3.49)
medianθ	0.40	0.46	3.20
95% CI.	0.21 - 1.40	0.24 - 1.64	1.42 - 5.86

Table 5.3. Accuracy of prospective duration judgements (θ) for story recall tasks

Overall therefore, the results demonstrated that head injury is associated with both reduced verbal recall and with reduced timing accuracy. This observation partially replicates the findings of the previous study, but in the present investigation there was also a significant effect of severity of brain injury on verbal recall, while timing accuracy was impaired only for the very severely head injured subjects.

AH Story
Time estimation accuracy
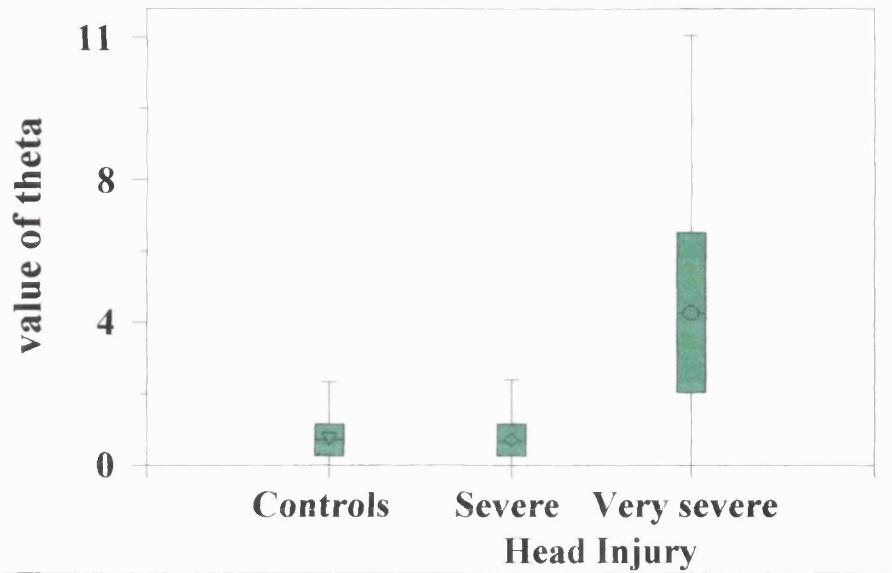
Figure 5.1 Accuracy of estimated duration for AH story

(mean, standard error and standard deviation)

PW story
Time estimation accuracy
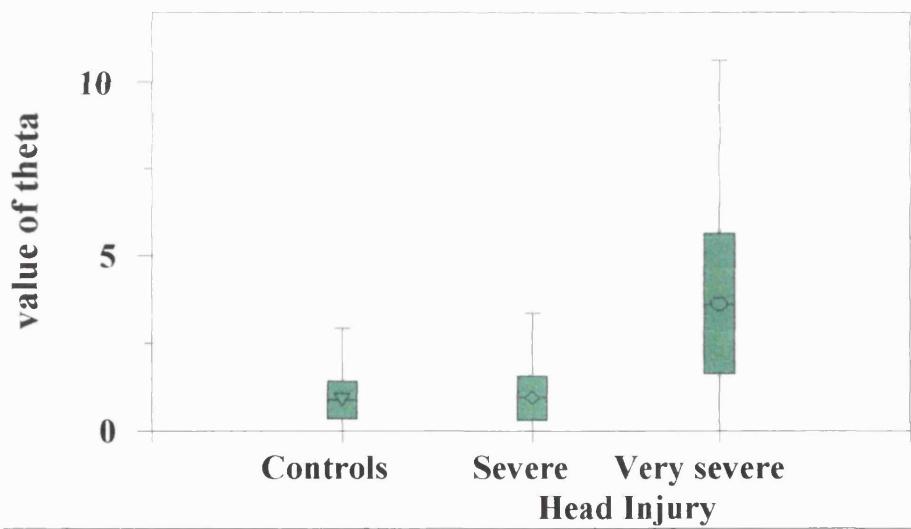
Figure 5.2 Accuracy of estimated duration for PW story

(mean, standard error and standard deviation)

5.4 Discussion

Consistent with predictions, the results demonstrated that the measure of story recall was sensitive to the presence and the severity of brain injury. In addition, it was also predicted that temporal coherence would form a facilitative structure for information processing. The results confirm that the controls and severely head injured subjects recalled more information from the narrative with greater temporal organisation, an observation entirely consistent with the original model of discourse processing (van Dijk & Kintsch,1983) which provided the impetus for the study.

Estimations of task duration by the head injured subjects were also significantly less accurate than were those of the controls. Although these observations suggest an association between the two indices of event recall and timing, there were no significant correlations between immediate memory score and timing accuracy for the AH or PW stories for any subject group. On closer inspection this is not surprising as the timing of the severe head injury group is as accurate as that of the controls. Only the very severely injured subjects are impaired with respect to estimated task duration. Therefore, on the basis of the present study it appears unlikely that subjective duration is derived directly from intrinsic temporal properties of the events in an interval.

Overall therefore the results show a general effect of head injury in timing accuracy in that the combined observations from the two head injury groups were significantly different from those of the controls. However, the data clearly show that some head injured subjects perform similarly to controls whilst the more severe group show gross disturbances of timing. As described in the Introduction, the use of memory-based tests in a prospective timing paradigm permits separate analysis of the effects of temporal organisation on both memory and timing, as prospective timing tasks are generally considered to be independent of the kind of long-term memory processes to which story

recall tasks may be sensitive (Shaw & Aggleton,1994).[4] Hence within groups there was no effect of temporal coherence on timing, despite a clear influence of temporal organisation on memory.

It remains to account for the observed equivalence in timing accuracy between controls and severely head injured subjects. The results correspond to outcome (d) in figure 3.1, in which the principal between-group difference occurs between the two groups of head injured subjects. Given that the two groups differ in terms of severity of brain damage, it could be argued that the disparities in timing are attributable to differences in resource limitations, with the very severe injury group having less processing resources available (see section 3.6). However this entails that the relation between amount of processing resources and task (in this case, timing) performance is markedly non-linear, which seems an uncomfortable assumption to make to explain the results. An alternative and more plausible account may be suggested in terms of the greater likelihood of damage to specific cognitive systems for the more severe of the two head injury groups. In other words, the more severely injured group are the more likely to have sustained severe frontal and subcortical damage which would undermine executive functioning. Their performance is therefore likely to reflect a combination of disruptions to different cognitive systems, to a greater degree than is the performance of the less severe head injury group.

In contrast with the tasks reported in the previous chapter, the present timing experiment was undertaken with tasks of much shorter duration (< 40 seconds). It is quite possible that timing over such short durations does not normally involve executive skills to any great extent, hence timing may be performed as accurately by many head injured subjects as by non head injured controls. This suggests a critical temporal limitation within which concurrent timing may be performed accurately by head injured persons (see also Fortin et al.,1993). Yet dysexecutive deficits may impinge upon this ability, as the central

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[4] It should be noted that the term 'prospective' in this sense refers to a procedure of on-line monitoring of temporal passage and is not to be confused with the similar but conceptually distinct process of prospective remembering.

executive component of working memory appears to have a temporal dimension which may be selectively impaired after head injury (Van der linden et al.,1992). Thus even within these temporal parameters of 30-40 seconds very severely brain injured individuals who are likely to have sustained severe multiple cognitive system damage appear to have problems in monitoring the passage of time.

Chapter 6

Attention and Psychological time:
The effect of task interruptions

6.1 Introduction

In chapter 2 it was recounted that William James first proposed the notion that there should be an inverse relation between remembered time and experienced time, such that overestimation of the former should accompany underestimation of the latter. This idea has been reiterated by many subsequent cognitive theorists and was given mathematical substance by Thomas and Cantor (1978). More recently however, some commentators have suggested that this kind of formulation is too simple and does not take into account other variables such as strategy, effort and task demands. For example, Macar (1996) reported that prospective duration judgements were influenced by stimulus regularity rather than simply by attention to task, as stimuli delivered aperiodically were associated with shorter time estimates. Somewhat contrarily, other studies have shown this effect to operate only for retrospective judgements (Zakay et al.,1994).

In chapter 3 the role of a Supervisory Attentional System (SAS) was introduced as a testable model of executive function with considerable potential neuropsychological validity. Thus, in a number of non-routine situations, effective regulation of behaviour often necessitates that attention is re-allocated by some central control system which, in terms of the Norman and Shallice (1986) model, is a role ascribed to the SAS. The implications of this process for the subjective awareness of time have not been previously addressed but are an important aspect of any comprehensive model of executive function. According to many accounts of prospective timing, any re-distribution of limited capacity attentional resources to task as task demands increase will compromise the monitoring of interval duration, which itself needs attentional mediation. Reduced attention to time could undermine task performance, especially when time constraints are operative.

Given that difficulty in attentional switching is well-established after head injury (Brouwer et al.,1989; Azouvi et al.,1996) one would expect poor concurrent awareness of time to be widespread amongst such subjects. If head injury is associated with difficulty in monitoring time while attending to task then two results should follow: performance should be less constrained by time-limitations, and prospective estimates of task duration should be reduced with a resulting decrement in accuracy. Surprisingly, there are no studies which have examined these issues although Schiffman and Greist-Bousquet (1992) reported that subjects undertaking an anagram solving task which was interrupted mid-way through were less accurate in judging task duration than were subjects who completed the task uninterrupted.

Unfortunately the solitary Schiffman and Greist-Bousquet (1992) study is very weak. It was conducted with few subjects, only one interruption, and the same subjects did not receive both interrupted and non-interrupted conditions, with seemingly different length intervals (though not specified) for each group. For clinical purposes a more life-like situation is necessary involving several interruptions, requiring subjects to monitor both the environment for perceptual cues to trigger an alternative action and the passage of time (Dobbs & Reeves,1996). To the extent that interruptions add to the total sum of salient events (Zakay et al.,1994) or constitute a form of contextual change (Block,1978; 1992), then prospectively estimated time experience should be less accurate and theoretically shorter than non-interrupted intervals of equivalent length. However, if attentional switching does not influence the overall number of relevant events in an interval, the interruptions should not affect experienced time.

In the method section below two information processing tasks are described, requiring numerical cancellation and lexical decision respectively. For each task three important differences compared to the Schiffman and Greist-Bousquet (1992) study should be noted. First, there are several interruptions throughout task execution, thus simulating a more real-life situation; second, the uninterrupted and interrupted intervals are of equal duration; and third, subjects perform the same task under interrupted and non-interrupted

conditions, thereby permitting a more direct comparison of the effect of task interruptions.

6.2 Method

Material

Subjects were administered two tasks. The first task was employed to examine the influence of processing speed on experienced time. This task comprised three versions of the information processing subtest from the Adult Memory and Information Processing Battery (Coughlan & Hollows,1985; forms A1, A2 and B1). These are standardised tests in routine clinical use for which good normative data are available. The three tasks were undertaken in three different conditions comprising a time production paradigm and two verbal estimation methods, one of which involved periodic interruptions from a countdown timer (see below).

A second, lexical decision task was devised to examine the relation between timing and cognitive skill. This task constituted some seventy words of approximately equal proportions of high and low frequency and of concrete and abstract nouns, typed (point size 16) across a sheet of A3-size paper (14.5" x 11.75"). The test comprised two forms, one of which (error version) contained 50% of the words spelled incorrectly. This error-ridden task and a no-error version were to be undertaken prospectively without interruptions; a further no-error version was to be adminstered in the interrupted condition. This arrangement was in order to permit the effects of task interruption to be discerned from those attributable to a general effect of task difficulty Unlike the information processing task, the lexical decision task was not adminstered as a time production task.

Subjects

In the present study a group of 13 severely head injured subjects and a second group of 10 very severely injured were recruited, alongside 12 age-matched orthopaedic controls.

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Controls and the severely injured patients completed the re-standardised NART (Nelson & Willison,1991), but it was not possible to administer this task validly to the more severely injured group due to the presence of acquired reading difficulties in so many (see also Rand et al.,1990). Both head-injured groups were administered a short-form of the WAIS-R, based on the original NART standardisation format (Warrington et al.,1986). The Full Scale IQ was used to compare with NART scores, as there is some suggestion that the re-standardised NART tends to overestimate Verbal IQ (Mockler et al.,1996). From table 6.1 below, summarising the clinical characteristics of the subjects, it can be seen that the two head injury groups are matched for current intellectual level on the WAIS-R, and that the severely head injured group is also comparable to the controls on the NART-R index of premorbid intellectual status.

	Orthopaedic Controls	Severely head injured	Very severely head injured	
Sex (M:F)	8:4	11:2	10:0	
Age (yrs.months)	41.4 (17.3)	37.4 (15.6)	40.5 (13.1)	
PTA (weeks)	-	8.1 (6.0)	32.3 (10.2)	**
Months post injury	-	14.5 (12.3)	47.7 (43.1)	*
NART-R FSIQ	108.6 (7.5)	102.4 (8.2)	-	
WAIS-R FSIQ	-	85.5 (10.8)	77.2 (8.5)	

Table 6.1 Clinical characteristics of subjects in task interruptions study

$* = p < .005, ** = p < .001$

Procedure: Information Processing task

The tasks described below were randomly introduced as part of a more general neuropsychological assessment. This included an irregular-word graded-difficulty

spelling test (Baxter & Warrington,1986) undertaken to provide an estimate of spelling ability as a possible index of lexical decision task difficulty. The number cancellation information processing task was administered under three conditions:

(1) Non-interrupted condition

Subjects were presented with the stimulus sheet, an A4 size array of three columns, each comprising 35 rows of five two-digit numbers (Information Processing form A1 of the test battery). Subjects were given the instruction to cross out or cancel the highest number in each row, and to work their way down the columns until they were told to stop. They were also informed that they would be asked to provide a verbal estimate of the task duration (which was the standard four minutes) upon task cessation.

(2) Interrupted condition

Using parallel form B1, the same information was given to subjects but they were also presented with an electronic timer which was set to go off at 20-second intervals. The subjects were not told the frequency with which the timer would be triggered but they were instructed that they had to stop what they were doing each time they heard the timer bleep, and to re-set it as demonstrated by the experimenter, before re-commencing the number cancellation task.

(3) Time production condition

Form A2 was used in this task, which consists of columns of paired four-digit and five-digit sequences, latter containing the same numerals plus one additional digit. Subjects are required to cancel the extra digit from the five digit sequence which is not present in the paired four-digit array. In this task subjects were also asked to complete the task *until they felt that two minutes had expired*, at which point they were to alert the examiner who would stop timing them.

In addition, subjects also completed the short (20 second) repetitive digit cancellation task which accompanies this subtest as a control for motor speed and thus allows calculation of speed of information processing from the above tasks.

Procedure: Lexical decision task

The lexical decision task was also adminstered in the same three conditions. That is to say, subjects were presented with three sheets of scattered words and instructed to search through them, highlighting any words they thought might be mis-spelled. Two minutes were permitted for this task.

(1) Non-interrupted (errorful) condition

An A3-size sheet of approximate seventy haphazardly arranged stimulus words was presented to the subjects. Exactly half the total number of these words were mis-spelt. Subjects were told to read through all of the words on the sheet in front of them and highlight any that they felt may be spelled incorrectly. At no time were they informed whether any of the words were incorrectly spelled. Before the task commenced subjects were also informed that they would be asked to verbally estimate task duration upon completion (in this case only two minutes were allowed);

(2) Non-interrupted (non-error) condition

In this condition all of the stimuli were correctly spelled, there were no errors for subjects to detect, though of course there was opportunity for them to make errors of commission. The same instructions were given to the subjects in the non-error condition, they were forewarned of prospective timing nature of the task (again two minutes were allowed).

(3) Interrupted (non-error) condition

In the interrupted condition the stimulus words were again all spelled correctly. Subjects were given the standard instructions, including advance notice of the prospective timing element. In addition they were presented with a timer and were told that they were

required to re-set the timer on signal (in this case at 10 second intervals). The task lasted for two minutes.

6.3 Results

The results were log. transformed in accordance with the argument given in chapter 4. In the analyses which are reported it may be assumed that parametric statistics were used unless otherwise indicated.

6.3 (i) Non-interrupted tasks

Table 6.2 summarises the information processing capabilities and spelling skills of the three subject groups, skills which form the background to the time estimation aspects of the tasks. Consistent with results from previous studies (Schmitter-Edgecombe et al.,1992; Gron,1996; Spikman et al.,1996) there was a significant difference between head injured and control subjects in speed of information processing (adjusted for motor speed) (F = 12.78 (1,32) p < .01) with the severe head injury group showing less reduction in speed than the very severe group (F = 7.33 (1,21) p < .05).

	Orthopaedic controls	Severely head injured	Very severely head injured
Adjusted processing speed score	61.3 (14.1)	46.8 (13.1)	23.4 (17.8)
(percentile rank)	50-75 %	10-15 %	< 2 %
Graded spelling score (max. 30)	21.3 (4.1)	19.9 (5.6)	10.2 (8.9)
(percentile rank)	50-75 %	25-50 %	20 %

Table 6.2 Information processing and spelling ability for all subjects (means and SD.s).

Table 6.3 below shows the lexical decision task scores for each group. As subjects varied in the amount of words they responded to during the two minutes which the task lasted, the scores are given as percentages of the overall number of stimulus words they scanned.

There was no significant difference between the head injured subjects and the controls in spelling ability although the very severely injured group did score notably worse on the graded spelling test than did the severe head injury group $(F =5.26, (1,32) p < .05)$ which raises the suggestion of acquired dysgraphia amongst the former. Although orthopaedic performance across lexical decision tasks under different conditions was highly correlated $(r = 0.914, p < .01)$, it was rather suprisingly not predictable from spelling test scores. Amongst the severely head-injured group spelling skills correlated with the misclassification of mis-spelled words on the Error task $(rho = 0.823, p < .05)$. There were suggestions of several other relations between spelling ability and lexical decision but these failed to reach significance.

	Orthopaedic controls	Severely head injured	Very severely head injured
Error task			
False positive errors	15.0 (15.7)	16.1 (5.6)	27.6 (36.7)
False negative errors	1.4 (2.3)	3.8 (4.3)	5.9 (11.8)
No error task			
False negative errors	5.1 (9.4)	5.9 (8.7)	8.1 (12.0)

Table 6.3 Error rates on lexical decision tasks for each subject group.

Table 6.4 below shows the time estimation accuracy of all subjects for the non-interrupted tasks. Inspection of the data for the non-interrupted information processing task (task a) shows a clear trend for reduced accuracy with increasing severity of head injury on this task. However, parametric ANOVA showed that there were no significant differences between head injured subjects and controls ($p > .3$) or between the two head injury groups ($p < .5$). It should be noted that the standard deviations are extremely large in this case which may well have reduced the statistical significance of the apparent trend, and hence the sensitivity of the task.

	Orthopaedic controls	Severely head injured	Very severely head injured
Task a Duration (sec)	240	240	240
Mean θ	0.54 (0.58)	1.00 (1.10)	1.52 (1.98)
Median θ	0.25	0.55	0.80
95% C.I.	0.08 - 0.99	0.22 - 1.79	0.01 - 3.04
Task b[1] Duration (sec)	120	120	120
Mean θ	0.72 (0.63)	0.49 (0.48)	1.31 (1.41)
Median θ	0.55	0.45	1.00
95 % C.I.	0.19 - 1.25	0.19 - 0.80	0.22 - 2.39
Task b[2] Duration (sec)	120	120	120
Mean θ	0.43 (0.44)	1.05 (1.22)	1.62 (2.30)
Median θ	0.38	0.50	1.12
95 % C.I.	0.11 - 0.74	0.31 - 1.78	0.03 - 3.27

Table 6.4 Time estimation accuracy scores (θ) for non-interrupted information processing task (task a) and lexical decision tasks (b[1] = no error; b[2] = error)

With regard to the non-interrupted lexical decision tasks: while there was no significant difference between the controls and head injured subjects as a whole in verbal estimation of the non-error task (task b[1] in table 6.4) ($p < .2$), the very severely injured group did show significantly less accurate time estimation than the severe head injury group ($F = 4.65$, $(1,21)$ $p < .05$). This is displayed graphically in figure 6.1 below.

Lexical decision task
Time estimation accuracy
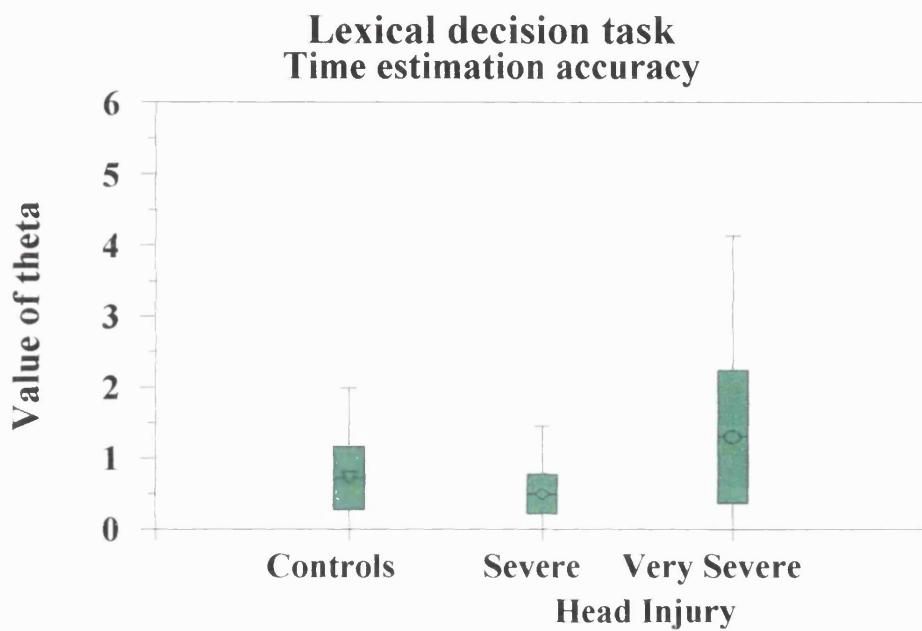
Figure 6.1. Timing accuracy (θ) for Non-Error lexical decision task.

As for the error lexical decision task (task b[2]), there is a clear trend for timing accuracy to deteriorate with increasing severity of brain injury such that mean accuracy of the very severe injury group differs from the control mean by a factor of four (see table 6.4 and also figure 6.2 below). Somewhat suprisingly ANOVA of the log. transformed data did not show any significant difference between the head injured subjects and the controls or between the two head injury groups, though again the standard deviations of the clinical groups are large which probably reduced the sensitivity of the task. Within groups, the error and no error lexical decision tasks were rated as equivalent in time, indicating that there was no effect of task difficulty on estimated duration. In order to explore a possible

contribution of the combination of both head injury and task demands, a two-way ANOVA was undertaken with head injury and task demands as independent variables. However, there was no significant interaction effect of task difficulty and injury severity. Although spelling ability as indicated by spelling test score did not predict time experience, for the severely injured group the number of false negative errors in the error condition (a potential index of task difficulty) did correlate with estimated duration ($r = 0.812, p < .01$).
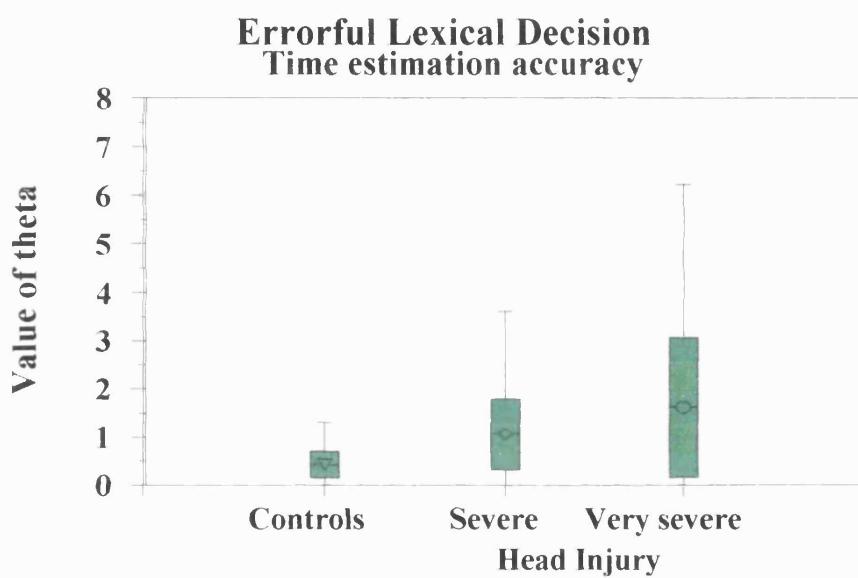
Figure 6.2. Timing accuracy (θ) on Error version of lexical decision task.

Time production task

The results from the time production tasks are summarised below (table 6.5) in terms of time estimation accuracy theta and the subjective time distortion ratio discussed in chapter 4 (the ratio of estimated time ψ to clock time t). There is a tendency for head injured subjects to over-estimate the passage of time (indicated by values of ψ / t greater than 1.0). The mean theta values show an even clearer trend towards increasing inaccuracy of temporal judgement after head injury. Unfortunately, as can be appreciated from the results table, the standard deviations are quite large and it was no surprise, though disappointing, that ANOVA failed to show a significant difference in

timing between the controls and head injured subjects ($p < .2$). In contrast with the absence of an effect of head injury on timing accuracy, there was an effect of head injury severity, as the very severely head injured group were significantly less accurate than the severe injury group ($F = 4.99$ $(1,18)$ $p < .05$).

	Orthopaedic controls	Severely head injured	Very severely head injured
Mean ψ / t	1.22 (0.40)	1.49 (0.57)	1.52 (1.11)
Mean θ	0.29 (0.36)	0.54 (0.52)	1.08 (0.80)
Median θ	0.15	0.44	0.75
95% C.I.	0.06 - 0.52	0.21 - 0.86	0.41 - 1.76

Table 6.5. Subjective time distortion and time estimation
accuracy values (θ) in the time production task.

6.3 (ii) Interrupted tasks

The results of the interrupted tasks are presented in table 6.6 showing mean time distortion and accuracy for each group across tasks. In the interrupted lexical decision task (task *a*) the number of false negative errors (correct words classified as spelled incorrectly) was inversely related to shorter estimates of task duration for the very severely injured group ($r = -0.661$, $p < .05$), suggesting that the fewer errors of this kind that were made, the shorter the task was experienced to be. ANOVA showed no significant time estimation differences between the controls and head injured subjects ($p < .2$), but there was a strong trend towards discrepancies in timing between the two head injury groups ($p = 0.08$). This is also illustrated in figure 6.3 below.

	Orthopaedic controls	Severely head injured	Very severely head injured
Task a Duration (sec)	120	120	120
Mean ψ/t	1.13 (0.42)	1.50 (1.02)	2.15 (1.91)
Mean θ	0.39 (0.36)	0.69 (0.92)	1.51 (1.67)
Median θ	0.29	0.18	1.44
95 % C.I.s	0.13 - 0.64	0.10 - 1.28	0.31 - 2.70
Task b Duration (sec)	240	240	240
Mean ψ/t	0.97 (0.31)	0.97 (0.49)	0.99 (1.02)
Mean θ	0.26 (0.16)	0.81 (0.77)	1.25 (0.97)
Median θ	0.25	0.50	1.37
95% C.I.s	0.13 - 0.39	0.30 - 1.33	0.24 - 2.26

Table 6.6. Subjective time distortion and accuracy of time estimation (θ) across groups for interrupted task (task a = lexical decision, task b = information processing).

In the information processing task (task *b* in table 6.6) the controls were notably more accurate than the head injured subjects in estimating duration ($F = 7.77$ (1,32) $p < .01$) while there was no reliable difference between the two head injured groups ($p < .3$). Despite the fact that the interrupted tasks showed clear inter-group differences in time estimation accuracy which had not been apparent on the continuous uninterrupted versions of the same tasks, no group of subjects gave significantly longer or less accurate verbal estimates of task duration under the interrupted condition, However, two-way ANOVA showed a strong trend towards an interaction effect, with head injured subjects being particularly susceptible to disturbed timing in the interrupted task. There was no

effect of the severity of injury on this susceptibility to the effect of interruptions (see figure 6.4 below).

Interrupted Lexical Decision
Time estimation accuracy
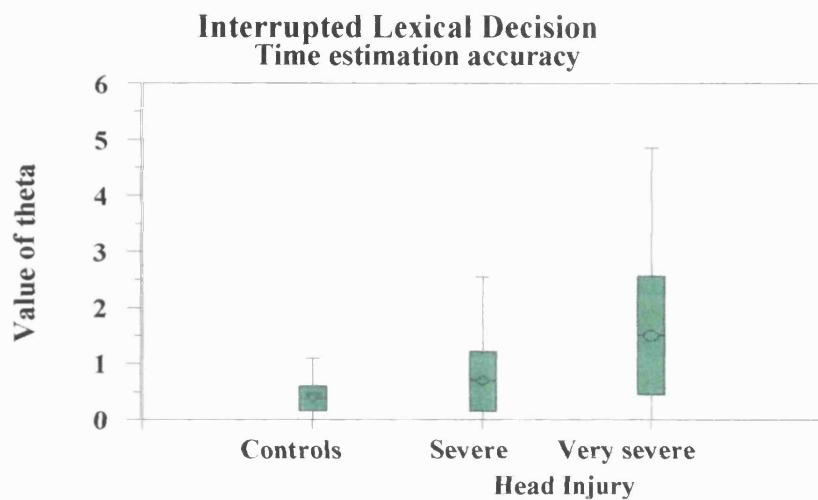
Figure 6.3. Timing accuracy for the Interrupted lexical decision task.

Interrupted task
Time estimation accuracy
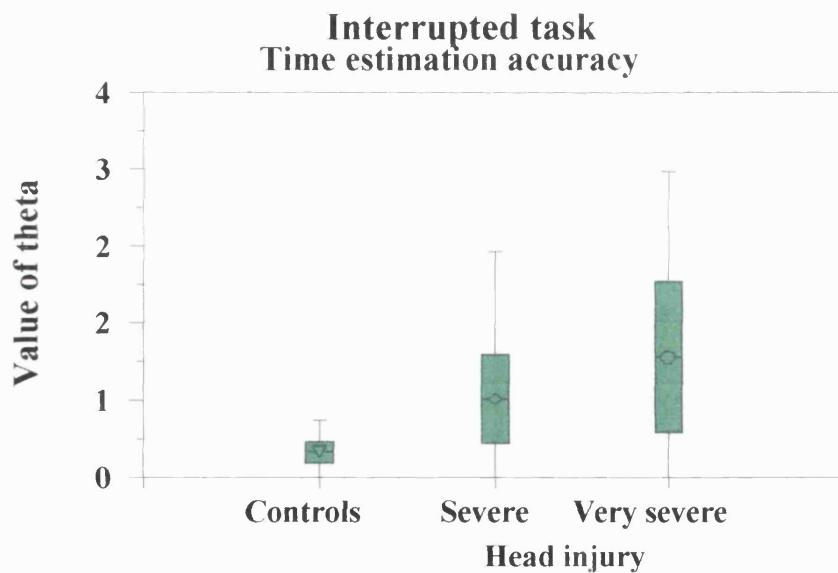
Figure 6.4. Group differences in accuracy of judgements of elapsed time during
interrupted information processing task
(plots show means, standard errors and standard deviations).

6.4 Discussion

The discussion of the experimental results will address firstly the neuropsychological deficits demonstrated by the subjects. The profile of time estimation performance will then be reviewed within the context of the underlying neuropsychological problems. In general, the studies confirmed that information processing deficits and, to a lesser degree, spelling difficulties are associated with increasing severity of brain injury. The fact that at least one statistically significant relation was demonstrated between the rates of false negative errors and spelling test scores (by severely head-injured subjects for the no-error condition) suggests that the lexical decision task was indeed sensitive to spelling ability, at least for those subjects with most difficulties.

There was in fact no difference in accuracy between the controls and head injured subjects in the no error lexical decision task, but there was a significant difference in timing accuracy between the two head injury groups. This suggests that only the most severely brain injured subjects had impaired awareness of time for the two minute duration of the relatively easy no error lexical decision task. By contrast, the error version of the task appears to elicit a more consistent trend towards increasingly inaccurate time estimation with increasing severity of brain injury (see table 6.4). In particular the very severe head injury group appear to be clearly deficient in time awareness, yet the discrepancies did not reach statistical significance. Nevertheless amongst the very severely injured there was a significant correlation between the number of false negative errors in the error condition and estimated duration which suggests that subjects who failed to identify incorrectly spelled words were less accurate in their time estimation. In contrast to attentional models of psychological time which predict an improvement in timing accuracy with less attention to task, this finding suggests that attentional decrements associated with brain injury may undermine both task performance and temporal monitoring (see also chapter 4).

With regard to the non-interrupted information processing task, the clear differences in information processing ability across the groups were associated with a trend towards

less accurate timing in the verbal estimation task (see table 6.3). In the time production task there was a significant difference in timing across all the groups but when controls were compared with the head injured subjects as a whole they were no more accurate. However, the fact that the severe group were significantly more accurate than the very severe group again suggests that only the most severely brain injured subjects experienced impaired temporal monitoring during performance of the two minute task.

No single task was estimated as significantly different in duration when it was performed under interrupted conditions than when completed continuously. However, the interrupted lexical decision task revealed a trend for increasingly inaccurate judgements of duration to be associated with increasing severity of brain injury. Yet again the very severe head injury group demonstrated a significant relation between the number of false negative errors and estimated duration, this time suggesting that subjects who omitted to identify salient stimulus items were also more likely to judge the task as shorter than their more accurate counterparts. Clearly therefore subjects do not pay less attention to task because they are heeding the time. It appears that very severely head injured subjects are failing to attend to both task and to time rather than due to an information processing bias towards time or task demands as current attentional accounts of psychological time require.

In the interrupted information processing task there was a significant difference in time estimation accuracy between the controls and head injured subjects which was broadly consistent with but statistically more robust than the trend from the interrupted lexical decision task. This result partially vindicates the original experimental hypothesis concerning the nature of task interruptions of concurrent timing ability. It will be recalled that there were significant differences between controls and head injured subjects in information processing speed, but whereas non-interrupted tasks showed a tendency for the only most severely brain injured subjects to perform less accurately than controls, the interrupted information processing task demonstrated a clear difference between head injured and non-head injured subjects. To a lesser extent the lexical

decision task demonstrated this as well though the discrepancies were not significant. Therefore, although it was stated above that no group exhibited significantly less accurate timing with the provision of tasks interruptions, the interrupted tasks (principally the information processing task) were the only tasks to distinguish between head injured and control subjects. It seems plausible that under 'normal' experimental conditions when subjects are allowed to complete tasks without interference from interruption, then only a very severe brain injury is likely to be associated with poor time estimation, as a result of generalised attentional decrements. In contrast, when tasks are made somewhat more ecologically realistic by introducing periodic interruptions then the first signs appear that (while task completion continues apparently unaffected) the incidental task of concurrent timing starts to suffer and time estimation accuracy deteriorates.

Although these results are encouraging there are both methodological and conceptual grounds why some of the findings suggest only trends and did not reveal unequivocally significant relationships. Perhaps the most obvious reason is that the sample size was inadequate given the sample variability to demonstrate more robust data. In addition the nature of the task interruptions may have been inadequate to disturb timing processes more severely. Certainly, in the terms of a central executive system the action of the switching-off of a timer in response to a signal occurring at regular intervals does not require much cognitive mediation and could conceivably be executed by a routine action programme with minimal attentional demands. In fact, this is the impression gleaned from observing the control subjects perform the task. Head-injured participants, by contrast, often found the periodic "bleeping" disconcerting and somewhat irritating. This qualitative difference in task performance was not always fully reflected in the results but it seems plausible that difficulties in switching attention by head-injured subjects may have even greater effects on psychological time than are evident in the present study. Such effects might be observed in the context of changes in task demands of a more attention-demanding and cognitively challenging nature. These modifications are addressed in chapter 7.

The plausibility of a cognitive neuropsychological account of the data appears to run counter to the internal clock framework, as the latter has typically entailed common timing mechanisms for both perception and action (Wing & Kristofferson,1973; Vorberg & Hambuch,1984). Thus some influence of concurrent motor acts on estimated task duration might well have been expected from an internal clock. However, such an effect might be avoided if time is represented at multiple levels throughout the cognitive system. An activation model which encompasses this notion was proposed by MacKay (1982, 1987) in which timing is the third component (after content and order) of cognition. MacKay's is a dynamic model in the sense that timing is distributed throughout the system, not imposed at one level (see also Summers & Burns,1990). Within such a framework it is entirely plausible that higher-level experience of duration may be unaffected by changes in temporal aspects of motor programming. These issues raises concerns about the testability of internal clock versus general cognitive accounts of psychological time. In the final section of the thesis (chapter 14) the data from the present study is considered along with results from other chapters in more detailed discussion of these issues.

Chapter 7

Attention and Psychological Time:
Changes in information processing

7.1 Introduction

In chapter 6 it was demonstrated on selected tasks that attention to time was inferior in head injured subjects compared to orthopaedic controls. This difference was statistically significant on the information processing task both for the production of time and the estimation of interrupted periods. In accordance with limited capacity attentional models of time (see chapter 2) these results suggest that concurrent timing involves divided attention which is typically compromised after brain injury. Although this tendency appeared to be exacerbated by task interruptions, there were no within-group differences in timing accuracy for interrupted and non-interrupted tasks. It appears therefore that the execution of an externally-triggered stereotyped response does not recruit attentional resources otherwise allocated to timing sufficiently to show a within-subjects effect. In cognitive neuropsychological terms it seems that the alarm which served in the previous study as a cue to interrupt on-going behaviour, merely triggered a behavioural response automatically or at least without continuing attentional monitoring. In other words, such an act could quickly be established as a "central set" (Mishkin,1964) during task performance. With reference to the Norman and Shallice (1986) proposal of the attentional modulation of behaviour, it may be presumed that the signal from the timer constitutes the trigger data-base and subsequent activation of the relevant schema (ie. the action of re-setting the timer) could be scheduled without recourse to supervisory control.

A possible flaw in the study reported in chapter 6 was that it targeted a behavioural change (a manual response to an auditory signal) without due consideration of the cognitive mechanisms controlling such a response. As discussed at the end of the previous chapter, there are theoretical grounds for considering that the interruptions

employed in the study entailed minimal cognitive load. Yet in everyday life behaviour needs to be regulated within a variety of timing constraints, many of which require rapid evaluation and problem solving (Shallice & Burgess,1991; Dimitrov et al.,1996). Therefore in seeking a real-life analogy it is probably more important to introduce changes to the information processing set or schema. On this basis a more realistic and potentially more effective modification would be to interrupt or shift conceptual thinking. The method adopted in the present chapter uses a modification of the Wisconsin Card Sorting Test (WCST) reported by Milner (1963) to be sensitive to flexibility of conceptual thinking and later revised by Nelson (1976).

The utility of the card sorting technique has been much criticised. Cerebral activation studies show that performance does not specifically involve frontal regions (Marenco et al.,1993; Nagahama et al.,1996), performance does not reliably distinguish between patients with CT or MRI evidence of structural lesions (Anderson et al.,1992) and it is not a useful diagnostic tool for frontal brain damage (Robinson et al.,1981; Axelrod et al.,1996). However, there is no doubt that this method remains a potentially sensitive tool to assess a subset of executive difficulties such as set-shifting and conceptual flexibility, regardless of lesion location. Furthermore, problems with concept formation, rule detection and conceptual flexibility, however they are assessed, are typically associated with anterior brain lesions (Wang,1987; Eslinger & Grattan,1993). Thus the card sorting paradigm seems an appropriate method to deploy with severely head-injured subjects to investigate the whether changing information processing demands affects their experience of time.

7.2 Method

Material

The modified 64-card version of the WSCT (Nelson,1976) was used in the present study. An important experimental modification was the insertion of coloured cue cards after every six stimulus cards. Upon these mauve-coloured cards were written prompts to change category sort, depending on the subject's existing sorting strategy. For example,

the card might contain the instructions: "if colour, change to number, if number change to shape or colour." In total ten such cue cards were inserted at regular six-card intervals. Additional cue cards were used for demonstration purposes prior to the study.

Subjects

Two groups of severely head-injured subjects, distinguishable in terms of injury severity and time post-injury were compared with an age-matched group of orthopaedic controls. These were matched to one group of head-injured subjects for estimated premorbid IQ on the re-standardised NART (Nelson & Willison,1991). The two head-injured groups were matched for current intellectual ability on a short-form WAIS-R. Table 7.1 shows the nature of the subjects groups in more detail.

	Orthopaedic Controls	Severely head injured	Very severely head injured	
Sex (M:F)	6:5	12:3	11:0	
Age (yrs.months)	40.4 (17.8)	37.7 (15.3)	40.4 (12.4)	
PTA (weeks)	-	7.3 (7.4)	31.5 (11.6)	**
Months post injury	-	12.7 (12.0)	63.6 (55.3)	*
NART-R FSIQ	106.9 (6.1)	102.3 (8.2)	-	
WAIS-R FSIQ	-	84.0 (8.6)	77.8 (13.8)	

Table 7.1 Clinical characteristics of subjects in the card sorting study.

$* = p<.01, ** = p < .001$

Procedure

The card sorting task was administered under two conditions, a simple-sort and a complex-sort. For the complex sort version (always administered first) the rationale for the task was briefly explained to the subjects. This took the form of instructions recommended by Nelson (1976) but with the important modification that subjects *were informed* that the cards could be sorted in three ways, ie. by colour, shape or number. In addition subjects were told that they would periodically come across coloured cue cards which would prompt them to change their sorting rule (at this point examples of the cards were provided and subjects role-played an illustration of a rule change). The task was begun when subjects showed an understanding of the general task instructions and the specific importance of the cue cards by demonstrating category sort changes in response to cue cards without prompting from the tester.

In the simple-sort task subjects were informed that there were no cue cards and the task was to sort the deck of cards using any single category of their choice.[5] This was always administered after the complex-sort task and with an interval of at least thirty minutes, during which time subjects were engaged in completing background neuropsychological measures. In both conditions subjects were forewarned that they would be asked to estimate the duration of the task, and it was suggested that they would therefore also need to keep mental track of the time. In contrast to the tasks reported in previous chapters, this study did not involve a pre-determined time interval. The duration of the tasks was determined by subjects' performance and therefore subject to some variability.

In general the tasks were completed satisfactorily by the controls and severely head-injured subjects. Unfortunately, some subjects amongst the very severely injured group did not appear able to follow the instructions for the complex sorting task, despite initially demonstrating their understanding, and these subjects required repeated

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[5] It was intended to ask subjects to perform some concurrent verbal short-term memory task to prevent them counting during the task. In fact this would have been impossible for most head injured participants and many controls spontaneously talked through the simple sort task (eg. by commenting on irrelevant stimulus dimensions as the cards were sorted) which suggested that they would not have been mentally counting.

assistance. This was done in three stages once they had made three successive errors. Firstly, they were simply prompted to read the cue cards more systematically, however if this proved ineffective they were shown the previous correct response, and finally on occasions it was necessary to place a card down correctly on their behalf in order to cue a run of correct responses. No subject whose results were retained in the analysis required this level of assistance on more than two occasions throughout the test run.

7.3 Results

Simple sorting task

The time taken to complete the simple category sort task and subjects' estimations of task duration are summarised in table 7.2 and figure 7.1 below. This includes mean subjective time distortion, mean estimation accuracy theta (and standard deviation), median values and confidence intervals.

	Orthopaedic Controls	Severely Head injured	Very severely Head injured
Completion time (seconds)	59.7 (42.9)	81.9 (32.4)	195.0 (83.4)
Mean ψ / t	1.00 (0.48)	1.20 (0.42)	1.96 (0.99)
Mean timing accuracy (θ)	0.44 (0.34)	0.75 (1.08)	1.27 (0.85)
Median	0.25	0.35	1.22
95% C.I.	0.18 - 0.71	0.03 - 1.48	0.22 - 1.04

Table 7.2 Summary of subjects' timing distortion and accuracy (θ)

on simple card sorting task.

The data on time to completion were log. transformed to ensure homogeneity of variance and then subject to parametric analyses of variance. ANOVA demonstrated a near significant difference between controls and head injured subjects in the time taken to complete the simple sorting task ($p < .07$). However, the very severely injured group were significantly slower to complete the task than the severe head injured group ($F = 13.8, (1,19) p < .01$). As indicated in table 7.2, the data on timing accuracy from subjects with a head injury show a widely skewed distribution, far in excess of the controls. Therefore this data was also log. transformed prior to parametric analysis. The trend towards less accurate timing amongst head injured subjects compared to controls which is evident in the mean and median time theta values (see table 7.2), failed to reach significance on ANOVA ($p = .10$). Similarly, the two head injury groups cannot be said to differ significantly in terms of their timing accuracy ($p = .14$), though the time distortion ratios (φ/t) were notably different ($F = 5.69, (1,19) p < .05$), suggesting that the most severely injured subjects tended to over-estimate task length to a greater degree than other subjects.

Overall, the controls completed the simple sort task in the shortest time and also tended to be the most accurate in estimating task duration. Clinically, the head-injured subjects are performing at an inferior level with respect to the control subjects (see figure 7.1) but in general these disparities were not statistically significant. It seems likely, given the variability of responses, that the subject numbers were inadequate for the required effect size.

Simple card sorting
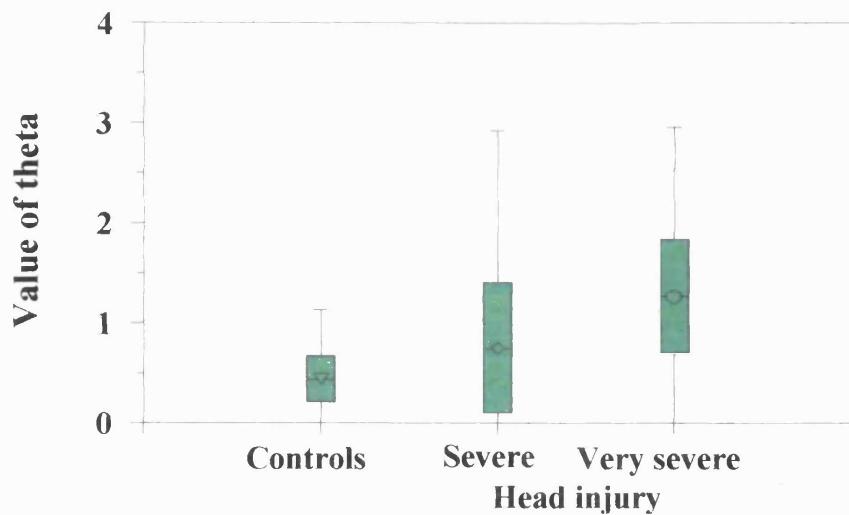
Figure 7.1 Timing accuracy of simple sorting task by controls and head-injured subjects (plots show means, standard errors and standard deviations)

Complex sorting task

Table 7.3 below shows the results for the complex category sorting task, in terms of completion time, subjective time distortion ratio and timing accuracy (see also figure 7.2). In contrast to the results from the simple sorting task, parametric ANOVA of log. transformed data showed that the control subjects were significantly quicker completing the complex sorting task than were the head injured subjects ($F = 18.6$ (1,32) $p < .001$). The severe head injury group also completed the task in less time than the very severe group ($F = 9.16$ (1,20) $p < .01$). The time estimation accuracy values were treated with similar regard because of the unequal variances between groups (see above) and the data were log. transformed prior to parametric analyses of variance. Somewhat in contrast to the results from the simple sorting task, the data from the complex card sort task, suggested that only the more severely injured subjects were showing inferior timing (see figure 7.2). Hence, the controls and severe head injury group were performing somewhat similarly, while the severe head injury group showed marginally greater accuracy ($p < .2$) than the very severe head injury group.

	Orthopaedic Controls	Severely Head injured	Very severely Head injured
Completion time (seconds)	110.9 (51.1)	190.3 (83.3)	342.6 (137.4)
Mean ψ / t	1.17 (0.67)	1.02 (0.51)	1.33 (0.85)
Mean time accuracy (θ)	0.63 (0.65)	0.72 (0.94)	1.18 (0.87)
Median	0.45	0.26	1.17
95% C.I.	0.22 - 1.04	0.14 - 1.29	0.51 - 1.85

Table 7.3 Timing distortion and accuracy (θ) on complex category-shift card sorting task.

Complex card sorting
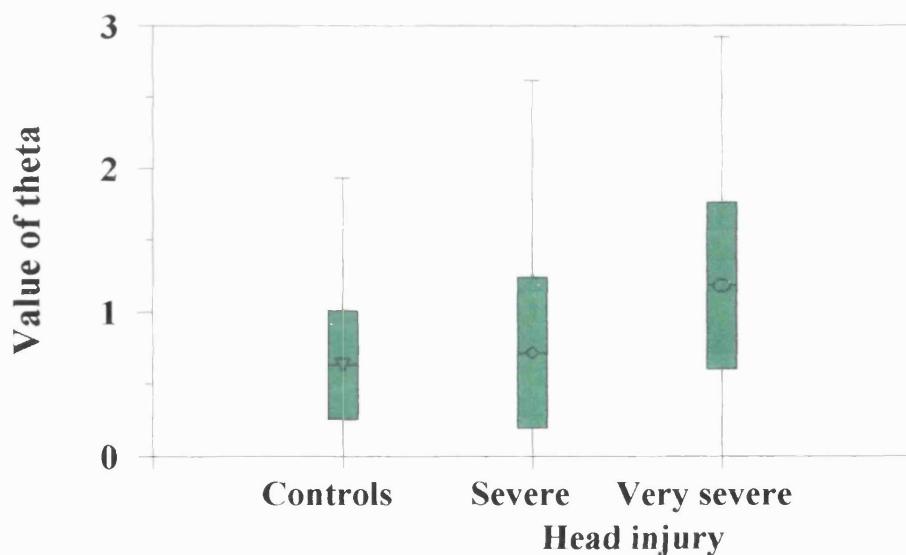
Figure 7.2 Estimated duration of complex category sorting task by for controls and head -injured subjects (means, standard errors and standard deviations)

Conceptual change and experienced duration

On a priori grounds, the multiple category-sorting demands of the complex sort task would seem to be more demanding than the simple sort task. However, a t-test of the completion times showed that this was not reflected in a significantly greater time to complete the task for controls. Thus, for the control group, the two tasks do not appear to have been notably different from one another. By contrast, the complex task took much longer to complete for the severely head-injured subjects ($t = 6.75$ (14) $p < .01$) and the very severely injured group ($t = 3.18$ (10) $p < .05$). Although some of the very severe head injury group had particular difficulties with this task (as described in the Method section above) and this undoubtedly contributed to the longer task duration, it should be noted that the severe head injury group also took appreciably longer than the controls. Thus it seems that task completion time is a sensitive index of the demands of changes in conceptual thinking in the complex card sorting task.

The distribution of subjective timing responses for each subject group is shown again, comparing across simple and complex sorting tasks in figure 7.3 below. The control subjects showed a marginal albeit statistically unimpressive trend towards greater inaccuracy under the complex sort conditions ($p < .2$). For the head injured subjects, a two-way ANOVA with head injury and sorting complexity as independent factors suggested but failed to confirm a significant interaction effect ($p > .2$). The head injured subjects were not impervious to the changes in task demands, as their increased completion times for the complex sorting task demonstrate, but such an increase in information processing demands were not reflected in reductions in timing accuracy.

Time estimation accuracy
Comparison across conditions
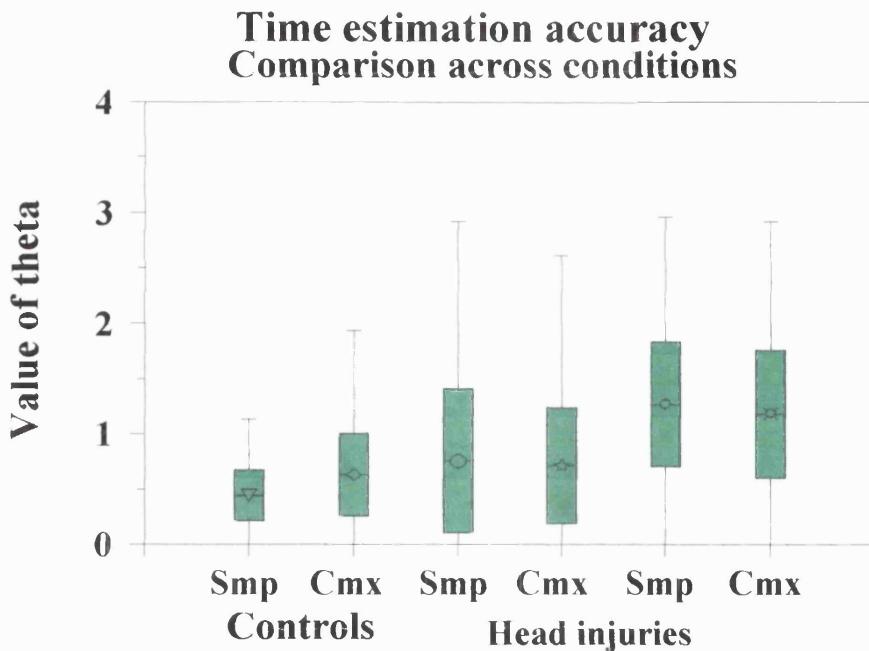
Figure 7.3. Accuracy of subjective time judgements across tasks for controls and first, severely, and then very severely head injured subjects. (Smp = simple sorting task, Cmx = complex sorting task).

7.4 Discussion

The results provide further evidence that the relationship between task demands and temporal awareness after brain injury is more complex than previous accounts of time experience have acknowledged. Although statistically weak, the data do show some apparently important differences in time estimation ability between individuals with a head injury and the controls. To the extent that these trends are consistent with evidence reported in previous chapters it seems likely that these signs are clinically significant. The failure to demonstrate that such disparities between experimental groups and controls are statistically reliable is probably compounded by insufficient sample size given the extent of intra-group variability, (and therefore the tasks may have been insufficiently sensitive to reveal statistically significant differences in timing with samples of the size employed) but it may also be an effect of the experimental design.

The control group completed the simple card sorting task slightly quicker than the head injured subjects and estimated its duration marginally more accurately. By contrast, the more complex sorting task was associated with a marked increase in completion time for the head injured subjects relative to the controls, with the very severely injured subjects being significantly slower than the severe injury group. Clearly therefore the extra demands of the complex sorting task were significant in distinguishing between head injured subjects and controls, and between different degrees of injury severity. However, these differences in task demands were not reflected in clearly discernible differences in timing across the two tasks in the experimental groups. This is contrary to established views of attentional influences upon psychological time, according to which subjective time is distorted when a task involves 'cognitive changes' (Martinez et al.,1994; Tsang et al.,1996). A larger sample may have brought a degree of statistical robustness to the trends already evident, but there are reasons other than sample size which may account for the results. Further discussion of these issues will be left until the final chapter.

SECTION THREE

Memory and Psychological Time

Chapter 8

Memory and Psychological Time:
The temporal context of past events

8.1 Introduction

Investigations of retrograde amnesia (RA) have shown that premorbidly acquired information is frequently impaired selectively (Sirigu & Grafman,1996) often in terms of semantic memory (Warrington,1975; De Renzi et al.,1987; Chertkow & Bub,1990) or memory for events (Dall'Ora et al.1986; Clarke et al.,1994) and autobiographical event recall (Baddeley & Wilson,1986). Memory for personal semantics (knowledge of facts about one's past) and retrieval of autobiographical incidents have been shown to be consistently impaired, highly correlated aspects of autobiographical recall (Kopelman, Baddeley & Wilson, 1989). However, Warrington and McCarthy (1988) reported a post-encephalitic patient, RFR, who showed a striking dissociation of recall between names and faces as facts and as temporal events. He had a relatively preserved store of information about famous people and friends but poor recall of events with which they were associated. It was argued that RFR showed a selective amnesia for events or scripts but preservation of knowledge for people within them (McCarthy & Warrington,1992).

RFR's deficit cannot be explained in terms of a selective impairment of contextual information by which details of events involving individuals are inaccessible or lost because he could discriminate familiar names as those of colleagues, neighbours or relations. Therefore some form of mediating schema was suggested as the normal process by which factual knowledge is integrated into event retrieval (Warrington & McCarthy,1988). Some suggestions as to the nature of this system may be gleaned from the account proposed by Hodges and McCarthy (1993) for the vascular memory deficit of PS, a former seaman who displayed a severe autobiographical memory deficit in which

recall of famous people and public events was relatively preserved. In explaining this pattern the authors assumed that information retrieval is accomplished using interpretative frameworks organised thematically in terms of major life events or time periods. Different kinds of information are presumed to be retrievable through multiple access routes into this organisational structure. Memory impairment may therefore be caused by defective thematic retrieval resulting in a temporally inappropriate interpretative context. This hypothesis appears to account for both PS's recollections and RFR's difficulties recalling information in temporal context. The utility of the thematic organisation framework has not been widely explored since it was proposed, but it appears to be a testable model of selectivity within autobiographical memory.

In view of the argument in chapter 3 that life histories help to sustain the concept of personal identity through time, the present chapter explores the importance of temporal context for autobiographical recall. It details the investigation of another Herpes encephalitis patient, SMH, who shows a similar pattern to RFR of selective impairment of memory for scripts in the context of relatively preserved knowledge for name familiarity. It is claimed that SMH's retrograde memory performance may be better interpreted as an impairment in using such reference frames for autobiographical recall. These observations are also consistent with the proposal that temporally organised frames of reference are crucial to an integrated narrative life-history.

8.2 Case History

SMH, a 53 year old stock controller, was admitted to hospital in November 1992, with with florid herpes simplex encephalitis. An MRI scan showed bi-temporal pathology, especially on the left side, extending into the left frontal lobe. In the context of a probable average level of premorbid ability (Nelson & Willison,1991) cognitive assessment demonstrated a Verbal IQ of 77 (Crawford, *et al.*,1992), frontal signs, amnesia and naming problems (but no category-specificity). She was episodically aggressive and profoundly disoriented. After treatment with Acyclovir and Dexamethasone she was discharged to a community rehabilitation facility in January,

1993. The experimental studies reported below were undertaken between this time and her discharge in May, 1993.

At the time of her discharge a neuropsychological re-assessment demonstrated some improvement in general intellectual functioning (Verbal IQ=85; Performance IQ=78), but she retained a severe memory deficit, scoring at chance level on Warrington's (1984) Recognition Memory Test for Words and Faces, and significant word finding problems (21/30 Oldfield & Wingfield,1965; 5/30 McKenna & Warrington,1980). Despite a marked improvement in her word fluency, poor performance on Shallice and Evans' (1978) Cognitive Estimates test (raw score 18) and perseveration and utilisation behaviour suggested persisting frontal dysfunction. An attempt to administer the multiple errands task (Shallice & Burgess,1991) was abandoned as it provoked significant agitation.

8.3 Evidence for a dissociation between *Actors* and *Scripts*

Following Warrington and McCarthy's (1988) account of fractionation within retrograde amnesia, several investigations were undertaken to establish the selectivity of SMH's memory impairment.

8.3 (i) Assessing Autobiographical memory

SMH was administered the Autobiographical Memory Interview (Kopelman, Wilson & Baddeley,1990). This test assesses recall of personal semantic information and memory for events associated with named individuals (autobiographical incidents) over three time periods (Childhood; Early Adult Life, and Recent Life). Her results showed a pattern of retrograde amnesia apparently similar to that reported for RFR (Warrington & McCarthy,1988; McCarthy & Warrington,1992). It is clear that within her generally impaired autobiographical memory she shows a striking inability to recall any incidents from any period of her life even where impoverished personal information is available (see table 8.1).

SMH was unable to provide information about her life events even for unique events involving very familiar people. For example, she could recall the year and place of her wedding but failed to remember that there had been no honeymoon. SMH showed no awareness of recalling an actual event to mind and there was little to suggest that she appreciated the relation between the recollection of factual details of an event and the event itself. This is suggestive of a lack of self-awareness to her memorising, or *autonoetic* consciousness (Tulving,1987). Although also showing poor performance for recent autobiographical semantics, the severity of her amnesia for *incidents* across time bears comparison with RFR who reportedly showed "selective preservation of semantic or context-independent knowledge of people with concomitant loss of memory for events involving those same individuals," (McCarthy & Warrington,1992,p.634).

	Personal Semantic	Autobiographical Incidents
Childhood	14/21 *(11)*	0/9 *(3)*
Early Adult Life	14/21 *(14)*	0/9 *(3)*
Recent Life	2/21 *(17)*	0/9 *(5)*

Table 8.1. SMH Autobiographical Memory Interview scores (cut-off scores also shown).

8.3 (ii) Memory for famous faces

SMH also had poor memory for contemporary faces, naming only 4/80 famous faces from recent colour photographs. She claimed to recognise a further 15 faces but could only offer background information (their occupation) for an additional 5/75 faces. RFR had also shown especially poor recall of faces (McCarthy & Warrington,1992 p.638), but the emphasis of SMH's pathology was left sided and therefore further tasks were

administered demonstrating that SMH retained a relatively preserved *name vocabulary* for people previously well known to her, in spite of her severe amnesia.

8.3 (iii) Memory for names

SMH was presented with the names of 46 famous people from the 1950s to the 1990s. Each name was presented in a three way multiple choice format with the two foil names having either the same Christian name or the same surname as the celebrity. SMH was able to recognise the famous person for 39/46 names, suggesting a relatively well-preserved store of famous names.

When presented in the same forced-choice format with the names of twenty close friends and relations, provided by her husband, SMH was able to recognise 18/20 names as familiar. Thus she has a fairly good appreciation of name familiarity for both famous people and individuals previously known to her. This information was also accessible to cueing (Sanders & Warrington, 1971): using a subset of the original 46 famous names SMH was able to select the famous one for 26/30 personalities from 1950-1990 when provided with the Christian name and initial letter of the surname only. She provided some additional information about the person's occupation in 23/30 instances. McCarthy and Warrington (1992) reported that RFR also showed preservation of basic personal semantic information. By contrast, when asked to indicate whether the correctly named celebrities were still alive, SMH scored 16/26, making four false negative and six false positive errors. The probability of obtaining this score by chance is 0.079 (Bhattacharyya & Johnson,1977), suggesting that SMH has some limited access to general public information about *actors*, a kind of store of role definitions, but severely impaired recall of specific incidents, even high profile events such as the death of a celebrity.

8.3 (iv) Memory for public events

Having established that she had severe difficulties recalling incidents involving familiar names, SMH was tested on her memory for public news events. Forty-one world-wide news events (1950s-1990s) were written on cards and shown to SMH in a three-way

multiple choice format, each with two non-real events and she was asked to indicate which incident had really occurred. She correctly recognised 22/41 events, score which is significantly above chance ($p < .005$), suggesting that she has impoverished but partly preserved ability to discriminate real and non-real events on the basis of familiarity. However she was unable to elaborate upon any items which she correctly recognised, consistent with a failure to recall more detailed script information. This confirmed that she has a severe memory deficit for public and personal incidents, evident on recognition as well as recall tasks.

8.4 Memory for Temporal Order

Information about event order is one form of temporal context known to facilitate memory (see chapters 3 and 5) and evidence of selective temporal order deficits suggests that temporal context may be particularly vulnerable to disruption. As post-encephalitic patients have been reported to show poor memory for the chronological relations between the limited number of events that they have been able to recall (Damasio et al.,1985; McCarthy & Warrington, 1992) it was important to establish whether this process was disrupted with SMH.

8.4 (i) Dating past events

In this task SMH was required to demonstrate first that she could arrange dates in chronological sequence and then to identify the corresponding events which occurred on those dates. Thus she was initially asked simply to place in chronological order twenty cards upon which were written dates (ie. specific years). These corresponded to news events of the past forty years, all of which she had recognised in the memory for public events task described above. She was able to do this simple sequencing task without difficulty. She was then presented with twenty cards upon each one of which was written a high profile news event spanning the years 1952 to 1991, and asked to match these event cards with the appropriate dates. Table 8.2 shows the accuracy of SMH's chronological ordering in comparison with results from seven age-matched controls (aged 52-66 years). Only 5/20 events were assigned to the correct decade, 17/20 events

(85%) were dated 1980-1991, and only the coronation of Queen Elizabeth II was located earlier than 1972, thus demonstrating an exaggeration of the normal telescoping effect in dating (Kemp,1988).

It is clear that SMH is much less accurate than control subjects in dating major public news events. She showed a tendency to locate events in the recent past and it is noteworthy that 4/5 correct responses were events that had occurred within the last ten years, the exception being the coronation of Elizabeth II.

	News events assigned to correct decade	Events assigned to adjacent decade	Events misplaced by two decades or more
SMH	5	10	5
Controls	15 (2.0)	4.5 (2.0)	0.5 (0.5)

Table 8.2 Accuracy of dating public events: SMH compared
to control subjects (mean and SD)

8.4 (ii) Judging relative order

Although SMH had severe difficulties relating event occurrence to points in time on a linear chronological scale, the issue as to whether she maintained accurate temporal relations between events was of interest. Therefore SMH was presented with a grid of nine public events (which she had previously identified but dated incorrectly) and asking her simply to indicate whether each incident was earlier or later than every other event on the grid. The questions necessitated a "later than" and an "earlier than" judgement in equal proportions, she was not required to date the events. SMH made 62/90 recency judgements correctly. As the probability of such a performance by chance alone is extremely small ($p < .001$) this seems to indicate that SMH is able to discriminate

relative recency amongst familiar public events. However, when half of these items were re-administered one month later she scored only 23/45 ($p < .2$) which suggests that her ability to judge recency is at best only partially preserved

Summary

In summary, SMH showed a relatively preserved vocabulary for the names of famous and familiar people which may constitute entries in a fact vocabulary (Warrington & McCarthy,1988). This information was accompanied by a minimal knowledge of their role, suggesting some residual familiarity for those she could not name. In contrast, she could not recall any incidents associated with the familiar names, even when such events (ie. their death) were arguably more salient than their former occupations. She has some sparing of memory for public events but little script memory for the details of such events. For those events with which she did seem familiar she showed some sparing of relative recency judgement in the light of poor memory for dating.

These results are broadly in keeping with the documented performance of RFR. However, the notion of impaired cognitive mediation originally proposed by Warrington and McCarthy (1988) is somewhat underspecified and inadequate as an explanation of the level of deficit. For example, both RFR and SMH showed preservation of some contextual information and cannot really be said to show the truly "...selective preservation of context-independent knowledge" that McCarthy and Warrington (1992) claimed. What is important in these cases may not be whether contextual information is preserved, but whether it is utilised in the retrieval process. Therefore an account in terms of the processes involved in autobiographical recollection may provide a more heuristic framework for subsequent investigation.

8.5 Thematic retrieval in personal memory

As an alternative conceptualisation, the distinction between temporal and non-temporal aspects of episodic recall may be reconsidered in terms of their hypothesised retrieval processes. In Hodges and McCarthy's (1993) model this implies the level of thematic

organisation involved. Accordingly, aspects of personal semantic information (dates, names, faces) are context free and may be considered to be recalled athematically by virtue of being associated with multiple presentations or recollections. In contrast, retrieval of script information is dependent on temporal context or organisation, for example, in recalling the chronological order of personal experiences or the duration or time lag of specific activities. It is assumed that activation of the appropriate thematic framework is required for this kind of temporally mediated retrieval. It may also be presumed that certain kinds of non-temporal personal information may have rudimentary contextual associations. This would include reference to atemporal details of specific events in time such as spatial aspects of events (eg. holiday locations, shops from which specific items were purchased). These may be presumed to be *subthematic* rather than athematic by virtue of their association with a unique event and were predicted by Hodges and McCarthy (1993): "highly specific or unique cues provide a means of entering the memory system at a level below that of thematic retrieval frameworks," (p.936). Thus it is possible to replace the script recollection vs. personal semantic dichotomy of episodic memory with a three-fold distinction based on the nature of the retrieval processes rather than the type of information recalled, ie thematic, athematic and subthematic retrieval. Evidence for the validity of these distinctions was sought in a further study with SMH exploring her responses to different kinds of memory-related questions.

8.6 Investigating thematic retrieval in autobiographical memory

Hodges and McCarthy (1993) reported the case of PS who suffered a vascular diencephalic lesion which resulted in a mnestic disorder characterised by faulty retrieval of an inappropriate temporal interpretative framework. The result of this proposed deficit in thematically organised recall was a confusion of autobiographical information such that events were recalled with the 'wrong' temporal context. If the activation of temporal thematic retrieval frameworks is a fundamental feature of how personal events are recalled then, regardless of the differences in aetiology (the importance of which is at this stage unclear), it follows for SMH as much as for PS that recollection should be most

impaired when required to retrieve information about the temporal context of events. Conversely, memory should be much better when these processes are not required. Furthermore, if it is possible to enter the autobiographical memory system at a level below the thematic retrieval frameworks, (ie. the inter-linked databases of factual information Hodges and McCarthy (1995) call schemas) then this kind of information should also be relatively spared. To explore these issues a series of sixty-one autobiographical questions were given to SMH on three occasions over a four month period, and separately to her husband (once only). These were administered in a semi-structured interview format which required her to provide as much information as possible in response to each item. The questions comprised 25 context-free personal semantic items (*athematic*), 17 *thematic* questions requiring a temporal reference to details of specific events, and 19 questions designated as *subthematic*, relating to nontemporal details of temporally specific events (see sample questions in ~~chapter~~ appendix A). For scoring purposes SMH was credited for each response consistent with that provided by her husband. As far as possible discrepancies in answers were presented to both parties and some consensus on the most realistic response was obtained, but this was undertaken only after the questions had been administered to SMH for the third and final time. The results are shown in table 8.3 as raw scores for SMH on each of the three testing occasions and for her husband.

The results appear extremely interesting, although they require careful scrutiny. One important caveat is that it has not been established that the questions are equivalent in difficulty. However, the variation in the performance of the control subject is not great and there was no ceiling effect, the control being was able to respond to between 79 % and 88% of the items. As they stand the data strongly suggest that there are differences between the three types of question. Some non-parametric analyses were undertaken to supplement visual inspection, though again they require cautious interpretation.

Wilcoxon Mann-Whitney analyses of the results suggest that SMH does not differ significantly from her husband in her recall of context-independent athematic

information ($p > .05$), but she demonstrates markedly impaired recall of thematic temporal details of specific events ($p < .001$) and also shows poor recall of non-temporal details of specific events, assumed to operate at a subthematic level ($p = .05$). Her subthematic recall is not significantly poorer than her memory for information recalled athematically ($p > .2$). By contrast, her memory for information presumed to be retrieved thematically is significantly impaired relative to her athematic recall ($p < .001$) but not her subthematic recall ($p > .05$). As no floor or ceiling effects were obtained these discrepancies are unlikely to be artefactual.

	Athematic	Thematic	Subthematic
SMH	17/25	0/17	8/19
	13/25	2/17	9/19
	17/25	2/17	7/19
mean (SD)	15.7 (2.3)	1.3 (1.2)	8.0 (1.0)
Control	21/25	15/17	15/19

Table 8.3. SMH and spouse: raw scores for Thematic,
Subthematic and Athematic autobiographical questions

8.7 Discussion: Thematic retrieval and temporal context

In the discussion which follows SMH's problems using temporal context memory will be considered in the context of her retrograde amnesia. Particular regard will be paid to the most useful neuropsychological conceptualisation of RA which takes account of the role of temporal organisation in memory retrieval.

SMH sustained bitemporal lesions and left frontal damage consistent with the pathological features of herpes simplex encephalitis. Neuropsychologically, she demonstrated fairly typical signs of intellectual blunting and severe anterograde and retrograde memory disorder. Her retrograde amnesia (RA) was characterised by preservation of all but the most recent verbal personal semantic facts (ie. not public events or faces but names of famous and familiar people) yet she was unable to recall any specific autobiographical incidents associated with these memories, even to the extent of knowing whether the persons were dead or alive. In this sense SMH is similar to McCarthy and Warrington's (1988) post-encephalitic case, RFR, showing an apparently disproportionately impaired memory for context-dependent incidents or scripts.

It was hypothesised that SMH should have greatest difficulty with the retrieval of episodic information which utilised thematic frames of reference (thematic recall), and least difficulty with facts which could be accessed without recourse to a temporal reference (athematic recall). Moreover, she should also have some problems in recalling non-temporal information which required the activation of specific thematic frameworks (so-called subthematic retrieval), but this deficit should not be as severe as her impaired thematic recall. Consistent with predictions, the results demonstrated that SMH had particularly impaired memory for temporal details of specific events, and that her recall of non-temporal details of events (via subthematic retrieval) was also notably poorer than that of her spouse but not significantly worse than her memory for generic context-independent information, presumed to be recalled athematically, and which was commensurate with her husband's memory performance. These data appear to support the elaboration of the Hodges and McCarthy model of retrieval processes in autobiographical recollection.

However, an alternative explanation which could account for the data is simply that the so-called subthematic retrieval questions were in fact a more or less equal mix of items tapping episodic and semantic memory. To test this supposition, the questions were given to five graduate or professional psychologists and they were asked to blind rate

each item as either semantic or episodic in nature. In each cases, subthematic questions were rated by each respondent as episodic in nature. Therefore the pattern of results produced by SMH cannot be explained as an artefact of question selection. In view of the fact that subthematic questions were designed to elicit recall through the activation of relevant temporal thematic frameworks, and in this sense the items were similar to the thematic questions, it is not at all surprising that given the choice, raters chose to designate them as episodic in nature rather than semantic. Therefore the results strongly suggest that SMH has a primary deficit in the utilisation of temporal thematic frameworks which facilitate for autobiographical retrieval.

In losing the temporal interpretative framework from her recollections SMH appears to have lost a crucial aspect of what makes them real for her. Unlike PS, SMH *knew* that certain autobiographical events had occurred, rather than remembered them. Like the amnesic MB (Dalla Barba,1993) she produced semantically coherent confabulation by inferring plausible but erroneous events. For example, when questioned further about her (false) claim to have gone on honeymoon after her marriage, she replied, "I suppose I must have."

The fact that PS could place names in temporal order suggests that order may be incorporated into an intact semantic system (perhaps in terms of trace strength). This may also account for the partial preservation of recency discrimination in SMH. However, both PS and SMH were unable to assimilate their present and recent experiences in appropriate temporal context. To do this appears to require activation of thematic retrieval frameworks, or at least those which are structured temporally, as there may be other means of organisation. In order to locate events in temporal context it seems plausible that access is required to some critical features of a mnestic representation which may be stored separately from other information. This is analogous to the specification of a description of the required memory (Norman & Bobrow,1979) and could be achieved by some form of temporal reference like Thematic Organisation Points (Schank, 1982) or thematic retrieval frameworks (Hodges & McCarthy,1993) such

that when the thematic organisational level is undermined, script information is inaccessible or contextually inappropriate if accessed. Whether this dysfunction is characterised as a deficit in a temporal or a spatial organisational framework seems at this stage to be equivocal. For example, whilst in the rehabilitation facility SMH thought she was at work and she would regularly answer the telephone in the nurses' office in accordance with this belief. Clearly she was using an interpretative framework which was both temporally and spatially inappropriate. In the case of SMH however, it may be speculated that her disorientation was primarily temporal in nature. Whereas she showed satisfactory spatial and perceptual abilities (there was no topographical amnesia), her ability to sustain a continuous record of events was severely compromised.

SMH's poor script recall can therefore be understood as a primary deficit in the thematic organisation of memory records as she has profound difficulties remembering temporal details about familiar events which are presumed to be recallable via temporally-organised retrieval frameworks. For the first few months of her illness SMH interpreted all events within the context of her vocational situation, its demands and time schedule. For example, she would insist on her keeping writing stationery accessible in case messages came through from work, she would answer the nurses' telephone as if at work, and she would be up and dressed early most mornings in anticipation of getting a lift her workplace. To the extent that this appeared to be a fixed interpretative framework it resembles the description of PS's default memory organisation theme. Later SMH showed no enduring preferential access to any one temporal reference frame, relying on information available athematically.

In stark contrast to her impaired recall of episodes which is assumed to require thematic activation, SMH showed relatively preserved athematic context-independent recall (presumably reflecting spared semantic memory) and some ability to recall information (schemas) subthematically. This was predicted, but not demonstrated, by Hodges and McCarthy (1993). They suggested that highly specific unique cues may enable entry to memory systems at a level below thematic retrieval frameworks. Hence PS's spared

knowledge of people and associated events hypothesised to be retrievable by using personal information accessed at a subthematic level. The present study went a step further along this line of reasoning and showed that SMH has less difficulty recalling atemporal details of specific events, suggesting too that this process may be accomplished without engaging the relevant temporal organisation framework. Her limited access to non-temporal episodic details is accountable in terms of a model whereby the recall of factual details of specific events can occur via temporally organised retrieval frameworks, linked to an atemporal context-independent system which also provides a means for recalling non-temporal data pertaining to specific incidents (Figure 8.1a below) or, alternatively, by parallel retrieval processing routes without hierarchical organisation amongst sub-components (Figure 8.1b below).

In terms of Hodges and McCarthy's (1995) model of principal memory access procedures, SMH has little access to event-specific episodic fragments which are normally are available thematically but she does have access to non-temporal details of event schemas. SMH's superior memory for atemporal generic (personal semantic) and non-temporal episodic information suggests that the two processes can function independently of the thematic retrieval level.

The fact that there is also a near equivalent decrement in athematic and subthematic retrieval processes may be explained either anatomically (as due to additional impairment because of the extensive nature of her brain lesion) or functionally, in terms of disrupted reciprocal influences among the components of autobiographical memory. In anatomical terms, PS suffered a well documented bilateral thalamic infarction; there was no structural evidence of prefrontal cortical damage yet he exhibited familiar signs of frontal involvement, including low motivation and poor insight. His deficits were attributed to disrupted communication between subcortical and pre-frontal regions yielding an information processing bias in favour of a faulty retrieval framework (see Burgess & Shallice (1996) for an account of frontal control processes in recollection). This account bears some resemblance to the disconnection model offered to explain

RFR's performance, and supports Parkin and Hunkin's (1993) suggestion that temporal judgements about pre-existing event memories may depend on intact frontal functioning. It has been suggested that bilateral temporal lobe pathology and additional frontal damage may produce especially severe retrograde amnesia (Kapur et al.,1992; Markowitsch et al.,1993) and it seems plausible that SMH's left frontal lobe lesion may have contributed to a more severe amnesia for script information than was shown by the other encephalitic patient RFR.

a   *b*

```
        ┌──────────────┐              ┌──────────────┐
        │  ATHEMATIC   │              │  ATHEMATIC   │
        │  retrieval   │              │  retrieval   │
        └──────────────┘              └──────────────┘
┌──────────────┐                   ╱            ╲
│  THEMATIC    │          ┌────────────┐    ┌──────────────┐
│  retrieval   │          │  THEMATIC  │    │ SUB-THEMATIC │
└──────────────┘          │  retrieval │    │  retrieval   │
        ┌──────────────┐  └────────────┘    └──────────────┘
        │    SUB-      │
        │  THEMATIC    │
        │  retrieval   │
        └──────────────┘
```
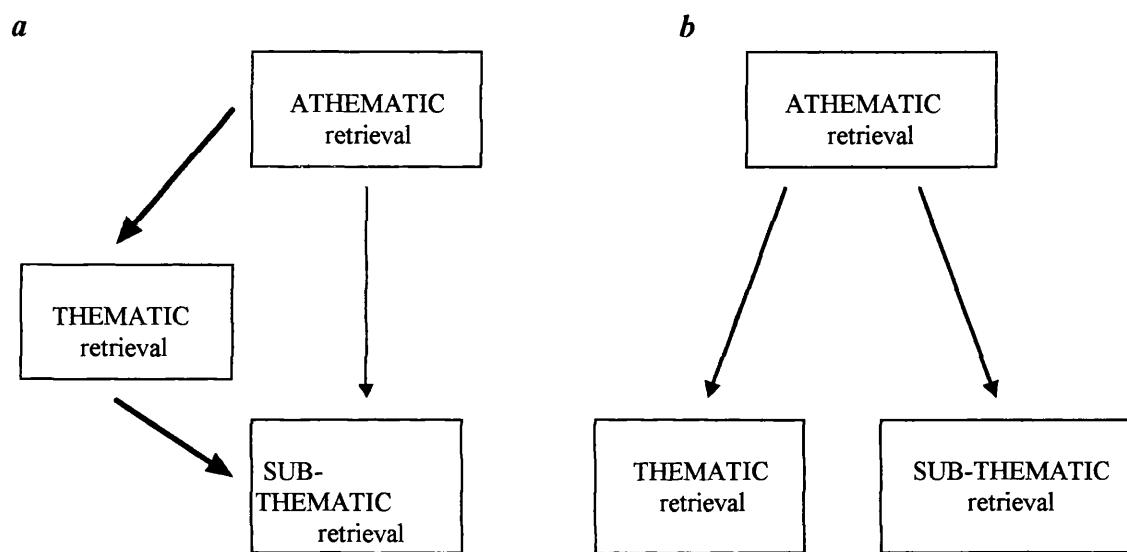
Figure 8.1. Possible relations between components of an Autobiographical memory system based on the organisation of retrieval processes

In post-script it is important to note also that SMH had severe problems coming to terms with her memory impairment. This appeared primarily to be because she appeared unable to remember her recent past, and was unable to interpret her current experience in the light of her residual knowledge for the distant past. Any threat to her fragile personal identity provoked hostility. This aspect of discontinuity in psychological time is discussed further in relation to the contribution of anterograde memory in the next chapter.

Chapter 9

Memory and Psychological Time:
Temporal experience in anterograde amnesia

9.1 Introduction

The previous chapter demonstrated that retrograde amnesia may be characterised by the inability to use temporal markers or reference frames in retrieval of episodic information for public and personal autobiographical events. Thus deficiencies in the temporal organisation of memory records may underlie memory loss for past events. In addition, earlier chapters have suggested that deficits in temporal information processing may also accompany anterograde memory impairment. The investigations reported have confirmed that accuracy of time estimation is *impaired* following severe brain damage. Head injured subjects also show poorer concurrent timing ability than controls, whether the task requires memory (chapter 5) or sustained attention (chapters 6 and 7). This deficit may be exacerbated during interrupted tasks (chapter 6).

Although it was argued in chapter 3 that psychological time encompasses many strands of neuropsychology, all the subsequent chapters have considered time estimation in relation to a single aspect of cognition, in isolation from other manifestations of temporal experience. However, from a clinical perspective the management of disturbances of psychological time requires a comprehensive evaluation of these disparate aspects of temporal experience. The present chapter demonstrates this approach in an exploration of disturbances of psychological time in an amnesic patient who showed marked deficits in the temporal regulation of her behaviour in a rehabilitation setting. The ensuing discussion incorporates the diverse aspects of time experience, hitherto reviewed

separately in the thesis. This includes the effects of task complexity, task interruption, knowledge about time, temporal reasoning and time estimation in a functional situation.

As discussed in chapter 3, the disturbances of psychological time cannot be appreciated in a clinical context without due consideration of the phenomenological aspects, not least as possible mediators of affective responses to disability. If Locke was right to assert that awareness of continuity of events over time is crucial to self-identity, then severe amnesia would be associated with a breakdown of the integrity of the Self (see also Talland,1965). Hence inquiry into the nature of psychological time may also yield insights into disturbances of personal identity. It is therefore timely to consider the relation between these different components of subjective time, an issue which not only forms the basis of the present chapter but is also the subject of the remaining chapters in the thesis.

The remainder of chapter 10 focuses on empirical investigations into the accuracy of time estimation in amnesia. This is then complimented by an exploration of knowledge about time and temporal reasoning. In discussion about the relation between these disparate aspects of cognition which comprise psychological time, mention will also be made of clinically-relevant phenomenological issues, especially with regard to personal identity.

9.2 Attention to time in amnesia: a single case exploration

This section details further investigations undertaken with SMH during her rehabilitation. The clinical and neuropsychological background to this case is detailed in the previous chapter, but it will be reiterated here that this 53-year-old lady sustained bilateral temporal lobe damage with left frontal involvement following acute herpes simplex encephalitis, which left her severe memory deficits and frontal signs. It is also worth re-stating that she performed at chance level on the Recognition Memory Test for words and faces (Warrington,1984) and showed very little explicit learning capability in her daily life. Although apparently able to tell the time she became agitated if kept waiting

for any length of time, she could not structure or regulate her behaviour according to time constraints and she seemed unable to appreciate the implications of temporal terms such as "half an hour from now" or "in fifteen minutes." A series of investigations were therefore undertaken, based on those described in chapters 6 and 7, to assess her understanding and experience of time.

9.2 (i) Experiment 1. Lexical Search

SMH and seven age-matched control subjects (mean age=56.7 yrs., SD= 5.1 yrs.) were asked to complete three lexical decision tasks to investigate the effects of task difficulty on experienced duration. These tasks are identical to those described in chapter 6 and were adminstered in the same manner. In each task a sheet of seventy words was provided and the subjects were asked to encircle any words which were spelled incorrectly. Only one word list contained misspellings (the "error" task), the other two lists were errorless: the easier "no error" task; and the non-error "interrupted" task, in which the subject had to terminate an audible timer every ten seconds. As in chapter 6 two minutes were allowed for each test. Failure to impose such a time limit leaves open the possibility that head injured subjects will simply take longer to complete the task, rather than pay more attention to it at the expense of attention to time (see discussion in chapter 7). The complex task was always administered first, followed by the interrupted task and then the final reading task. The lists were presented to SMH approximately twenty minutes apart during routine psychological testing on six occasions over a five month period. Table 9.1 shows the verbal estimates of duration for the three tasks both as a ratio of the actual time (time distortion ratio ψ) and in terms of overall accuracy (θ).

Parametric and non-parametric analyses of variance confirmed that there were no within-task differences between SMH and the control subjects in accuracy of time estimation. This suggests that SMH was just as accurate as the controls in estimating task duration. In fact, she appeared to be notably more accurate on the error and interrupted tasks (see table 9.1, as her scores were outside the control group range. However, these results are based upon multiple observations from SMH but single recordings from each of the

controls, a method which is likely to increase variability amongst the control group, and thus produce a spurious suggestion that SMH is the more accurate in estimating time. This issue is discussed in greater detail in the discussion section.

	Error task	No error task	Interrupted task
SMH			
Distortion ratio (ψ/t)	0.95 (0.30)	1.44 (0.17)	1.00 (0.00)
Accuracy (θ)	0.16 (0.19)	0.44 (0.17)	0.0 (0.00)
Controls			
Distortion ratio (ψ/t)	0.78 (0.38)	1.12 (0.46)	1.28 (0.52)
Accuracy (θ)	0.58 (0.87)	0.46 (0.40)	0.56 (0.37)

Table 9.1 Timing accuracy and ratio of estimated time to clock time
in lexical decision tasks (actual time = 2 minutes)

With regard to the direction of the estimation bias, the controls significantly underestimated the duration of the error task compared to the non error task ($t = 2.35$, (6) $p < .05$), although they were equally accurate on both tasks. This is consistent with a tendency to pay more attention to the task in the error condition. SMH also showed reduced time estimations for both the error task ($t = 4.46$, (6) $p < .05$) and the interrupted task ($t = 4.99$, (5) $p < .05$), relative to the non-error task. The magnitude of this change in duration estimation was not significantly different for SMH than the controls, showing that SMH was equally sensitive to increases in task effort and somewhat more sensitive than the controls to the effect of task interruptions. This general finding that interrupted and error manipulations tend to reduce time estimations is in keeping with suggestions that extraneous events and task complexity detract attention from on-going monitoring of

passing time. This effect is not necessarily reflected in timing accuracy if a task is originally over-estimated, though the mean theta values from the controls do show a minor decrement in accuracy with increasing task demands.

9.2 (ii) Experiment 2. Digit Cancellation

SMH completed the Information Processing tasks from the Adult Memory and Information Processing Battery (AMIPB, Coughlan & Hollows,1985). These tasks are described in detail in chapter 5. Four minutes are allowed in which the subject has to complete as many items as possible. On form B1 SMH was asked to work on the task until she felt that two minutes had elapsed (a time production task). On forms B1 (standard task) and A2 (interrupted task) SMH was forewarned of the need to provide an estimate of the task duration, but additionally for form A2 subjects were instructed re-set a timer which was set to signal every twenty seconds (see chapter 5). Each task was given to SMH on five occasions over several weeks, and once each to six age-matched controls. The results are shown below in table 9.2.

	Time production task	Standard task	Interrupted task
SMH			
Estimation ratio	1.28 (0.31)	0.55 (0.11)	0.84 (0.36)
Value of θ	0.28 (0.31)	0.83 (0.34)	0.48 (0.20)
Controls			
Estimation ratio	1.18 (0.56)	0.91 (0.38)	0.89 (0.18)
Value of θ	0.40 (0.37)	0.47 (0.22)	0.17 (0.29)

Table 9.2 Time estimation and time production during

Information processing tasks (actual time = 4 minutes).

Analyses of variance again confirmed that there were no within-group differences in timing accuracy across tasks for either SMH or the controls. Subjecting the ratio scores to analysis of variance suggested that there was an overall effect of task demands on experienced time for the control subjects ($F = 12.06$, $(1,9)$ $p < .01$) but the more conservative post-hoc F-tests revealed no significant between-task difference. However, when comparing only the response tendencies of the control group in standard time estimation and time production paradigms, then the controls significantly overestimated task duration by the method of production ($t = 4.17$, (6) $p < .05$) compared to a slight underestimate standardly. Thus these results are internally consistent (see chapter 2 for an account of the reciprocal relation between time estimation and time production).

SMH did not demonstrate any difference in timing accuracy across tasks or in comparison with the controls on any specific task, although a t-test comparing her performance on the standard task with that of the controls showed a non-significant tendency ($p=0.08$) for SMH to underestimate the duration of this task relative to the controls. In keeping with the "normal" timing effect demonstrated by control subjects, SMH also exhibited significant overestimation of time by the production method ($t=6.920$, $(df,5)$ $p<.01$) relative to the standard task. There was no effect of task interruptions on experienced time. Overall, even though there was a suggestion that SMH experienced the standard task as shorter than did the controls, there was no evidence of any difference in timing accuracy.

9.2 (iii) Experiment 3. Category Card Sorting

SMH was given the modified card sorting task described in chapter 6. This task has been revised from Nelson (1976) such that a coloured cue card is encountered at six-card intervals which instructs the subject to change to another specified category sort (colour, shape or number). In the simple version SMH sorted the stimulus cards under the key cards according to a single category of her choice, while in the complex sort version she was instructed to obey the cue cards. The tasks were administered on four occasions to SMH and once each to six age-matched controls. Task durations were prospectively

estimated. There was no time limit to this test but on comparing mean completion times controls tended to be quicker than SMH for both simple sorting and complex sorting. Table 9.3 shows both the verbal estimates of their relative durations in relation to actual time (time distortion ratio, ψ/t) and overall timing accuracy (θ) for both groups.

Repeated measures t-tests demonstrated that the control subjects were equally accurate in judging time across tasks whereas ($p > .1$) though surprisingly, SMH showed a slight tendency to be more accurate at judging the duration of the complex sort task ($t = 3.41$, (2) $p > .07$). Nonetheless SMH significantly under-estimated the duration of the complex card sorting task compared to the simple sort version ($t = 4.757$, (2) $p < .05$). This is in keeping with the results from experiment 1 suggesting an effect of task demands in shortening experienced duration for SMH.

	Simple sort task	Complex sort task
SMH		
Task length (sec.)	68.5 (3.5)	156.0 (24.0)
Distortion ratio (ψ/t)	2.00 (0.44)	0.78 (0.09)
Accuracy (θ)	1.00 (0.39)	0.28 (0.13)
Controls		
Task length (sec.)	50.0 (11.0)	106.5 (13.8)
Distortion ratio (ψ/t)	1.29 (0.58)	1.41 (0.68)
Accuracy θ	0.66 (0.45)	0.71 (0.50)

Table 9.3 Prospective time estimations of category sorting tasks.

The seemingly inconsistent observation of SMH's increased accuracy with greater task demands is most likely to be artefactual, as discussed below. Similarly, there is a

tendency ($p < .20$) for controls to be more accurate than SMH in estimating the duration of the simple sort task, but this is reversed for the complex task where it appears that SMH is more accurate ($p < .10$). Again, however, this latter result is most likely due to an artefact of the estimation procedure (see below).

9.2 (iv) Summary of results of duration experiments

There is some evidence that more complex tasks are associated with reduced estimations of task duration, even in the context of similar levels of timing accuracy. This was apparent in experiments 1 from the control subjects on the error task and from SMH in both error and interrupted tasks. Similarly, in experiment 3 SMH significantly under-estimated the duration of the complex sort relative to the simple sort task. Results from experiment 2 were generally internally consistent in so far as a tendency to under-estimate duration verbally was associated with the likelihood of overestimating duration by method of time production. Again, there was a tendency for SMH to under-estimate standard task duration relative to controls, though showing no difference from them in timing accuracy. By contrast, there was a tendency in experiment 3 for controls to be more accurate then SMH in estimating the simple sort task.

In general, SMH did not show significant impairments in timing accuracy despite being tested over periods of time which Kinsbourne and Hicks (1990) suggested should result in performance decrements from amnesic subjects. The results could therefore be interpreted as showing a much greater intact window of psychological time which could be monitored accurately by SMH (as suggested by Shaw and Aggelton,1994). Yet Shaw and Aggelton (1994) reported normal timing accuracy amongst post-encephalitic amnesics for up to one minute only; the experimental task durations employed above may reasonably be expected to have exceeded SMH's relatively intact short-term memory capacity. An alternative explanation for the results lies in a possible response bias in relation to the durations of the different tasks employed. Task durations comprised one minute (experiment 3), two minutes (experiment 1) and four minutes (experiment 2). Examination of her verbatim responses revealed that SMH tended to

give verbal estimates around the two to three minute mark and that "a couple of minutes" was her modal response. This would certainly account for her tendency to grossly overestimate tasks of one minute's duration (experiment 3) while tending to underestimate tasks of four minutes (experiment 2).

The data also reveal a tendency for more complex information processing demands or task interruptions to be associated with a reduction of estimated duration from SMH, to a greater extent than shown by the controls (experiments 1 and 3). Again this is only evident for tasks of one or two minutes' duration and the statistical validation of these effects is weak. Nevertheless, given the small data sets involved and the risk of type II errors it is probably unwise at this stage to disregard trends in the data. A provisional interpretation of the above experiments is that SMH shows a tendency to experience short-intervals of time (ie. 1-2 minutes) as passing slowly but her amnesic deficit renders it difficult for her to have any awareness of temporal passage over longer periods and she relies on a fixed response set. In this context it is interesting to note that Shaw and Aggleton's (1994) study revealed a significant correlation between time estimation and performance on the cognitive estimates test for their seven Korsakoff's amnesics but not the three post-encephalitic cases.

9.3 Towards understanding psychological time in amnesia

In a neuropsychological context the above results are broadly in keeping with those reported from other memory-impaired subjects, suggesting that attention to time may be compromised, especially during performance of complex tasks. Such activities may either be timed less accurately or under-estimated or both. In some respects SMH did not demonstrate the grossly impaired awareness of time that she displayed in everyday contexts. Nevertheless, the experimental studies yielded some interesting observations. In experiment 1, both SMH and the controls underestimated the more demanding error lexical decision task compared to the non error version. This suggests that all the subjects were sensitive to the detrimental effect of extra task demands upon concurrent timing. Only SMH however, also showed this effect on the interrupted task. This

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sensitivity after brain damage to task interruptions was also raised in chapter 6. In experiment 3 SMH also showed a significant reduction in timing distortion with the more complex sorting task (resulting in greater accuracy than on the simple sorting version) which is consistent with an effect of increased task demands detracting attention from timing. Although it has been suggested that this result is due to a response bias, the fact that the response bias is operative is still testimony to the fact that SMH's timing is disturbed to a greater extent than for controls by increases in task demands.

The absence of more significant timing deficits from SMH is interpreted largely as a consequence of experimental design. The procedures employed did not control for the possible compensatory strategies adopted by SMH for intervals longer than the one minute which seemed to exceed her concurrent timing ability. Thus she appeared to give plausible, almost colloquial, responses for several tasks which may be seen as an adaptive strategy in its own right for someone who was disoriented in time. Such a strategy entails a degree of reasoning ability and in less formal circumstances (when time is unlikely to be measured to the nearest second, as it was in the experiments) then it would undoubtedly have been very effective. In terms of the cognitive skills which contribute to psychological time, this suggests that SMH was able to deploy some reasoning skills to good effect. Thus she was able to utilise comprehension of temporal terms (related to semantic memory) to infer solutions to problems (utilising executive skills). In addition, there were other indications of a role for semantic memory processes in SMH's temporal awareness. For example, despite having little appreciation of the passage of time over periods of several hours, she could still tell the time (presumably due to intact semantic memory - see chapter 11) and compensated reasonably well by this means.

In summary, the results provide further evidence that time estimation studies with individuals with severe cognitive dysfunction do not readily equate to the results from healthy samples. The present investigations lends credence to the view that estimated time is not based solely on experience but incorporates other factors such as expectation,

past knowledge, plausibility and reasoning. It therefore becomes difficult to encapsulate the results within an single model of time experience. Further discussion of these conceptual issues is left until the final chapter 14, the next two chapters consider in more detail the role of memory in psychological time.

Chapter 10

Memory and Psychological Time:

Contextual memory and remembered duration

10.1 Introduction

In chapter 2 a number of models were described which purported to account for aspects of remembered duration. The failure of Ornstein's (1969) storage size analogy to distinguish between stimulus complexity and complexity of information processing led Block and Reed (1978) to propose that memory for changes in events rather than events themselves underlied retrospective duration. As discussed in chapter 3, aspects of contextual information processing have been used to examine normal memory performance and as an index of clinical memory impairment. The present investigation utilises Baddeley's (1982) notion of interactive and independent context to examine the influence of memory for target material and different forms of contextual information on estimates of remembered duration.

The rationale for using a recognition memory task for this purpose is detailed in chapter 3, but given that recognition memory is widely impaired after moderate to severe brain damage (Millis & Dijkers,1993) one would expect recognition memory performance to be related to severity of brain injury. As well as showing inferior recognition memory, the evidence of previous chapters suggests that head injured subjects would also be less accurate in their estimations of the task duration. Some suggestions as to the nature of this relationship between recognition memory and remembered duration can be gleaned from models of psychological time. Both internal clock models and the original storage-size account would predict that estimated task duration would be related to memory for stimulus events. In this case one would expect that remembered time would be a function of either total recognition memory score. Those subjects with poorest memory performance should therefore be underestimating the task duration relative to subjects

scoring higher. By contrast, if remembered time depends on memory for contextual information, then one should expect that subjective duration would be related to memory for context (and not performance in the no-context condition). However, if context affects duration by virtue of its impact on memory, then estimated duration should be related to memory performance in the interactive but not the independent context condition.

10.2 Method

Material

Fifty words were selected from the Thorndike-Logue (1944) corpus, 25 high frequency words (A or AA) and 25 low frequency (<25/million). All the selected words contained shorter embedded words within them. Some of these were phonologically equivalent as both individual words and part of the larger word stimulus, for example GAL-*VAN*-ISE, IN-*DUST*-RY, and some were phonologically different: E-*NAME*-L, AP-*PARENT*-LY (the hyphens have been introduced for clarity, they were not present on the stimulus cards). The embedded words were printed in black ink, whereas the remaining peripheral letters of the word were printed in red, on laminated green, blue or yellow card (3.5"x 5"). On the grounds that they might well change the nature of how the stimulus is encoded, the flanking letters were intended to comprise a form of interactive context in accordance with Baddeley's (1982) proposal. The background colour of the cards represents a dimension of independent context.

A second set of 50 words pairs constituted the recognition set. In this set stimulus words were presented in one of three recognition conditions. In the Verbal Context condition, the target word was presented embedded in the longer word but the flanking letters were also printed in black rather than red (eg. AT-*TENT*-ION presented as ATTENTION). The target and distractor words were presented on white laminated plastic card. In the Colour Context condition, the target word was presented without the flanking letters of the longer word (EG. OB-*SOLE*-TE presented as SOLE), but on green, yellow or blue

cards according to the background colour of the original presentation stimulus. In the No Context condition, the target word was also presented without the flanking letters to the original stimulus and on white card. In all cases target words in the recognition set were paired with a frequency-matched distractor, half of which also had potential embedded words within (not used in the original presentation set).

Subjects

In the present study 12 control subjects were compared with a group of 12 severely injured and 12 very severely injured subjects. As for previous experiments, two groups of severely head-injured subjects and an orthopaedic control group were enrolled in the study. The controls were matched on premorbid IQ (re-standardised NART) with the severely head-injured group, and the two head-injured groups were matched on current intellectual ability (WAIS-R). The clinical characteristics of the subjects are summarised in table 10.1.

Procedure

Subjects were presented with a 50-item forced-choice verbal recognition memory task. In the presentation phase, single words were printed on coloured laminated cards (either blue, yellow or green background). Each word comprised a longer word within which was an embedded word in black, as described above. Participants were told that they would see a number of words with another shorter word written inside in black ink, and that they were to read out loud the word in black. They were also forewarned that they would be tested on how many of the black words they could remember in the form of a two-choice discrimination task, immediately following initial presentation of all stimuli. They were *not* told that they would also be asked to estimate the duration of the task. Each word was presented for three seconds, subjects being prompted to read aloud the word if necessary, and corrected if they read the whole word rather than the embedded word. In the recognition phase two words were presented on each card. These comprised the target word and a distractor, in the presence of independent or interactive context or without contextual information, as described above. The word pairs were

matched for frequency, and in approximately half of the recognition cards both stimuli on the card contained embedded words. Subjects were requested to identify which word they had previously seen and were reminded that the letters formerly in red were now also in black, thus they might have to look within a word to seek the one they had previously read. At the end of the task, subjects were requested to estimate how long they thought it had taken them. They were asked to be as specific as possible, and told not to worry if they were unsure, but to hazard a guess if necessary.

10.3 Results

The background data on the subjects is summarised in table 10.1 below.

	Orthopaedic Controls	Severely Head injured	Very severely head injured
Sex (M:F)	7:5	10:2	12:0
Age (yrs.months)	41.4 (17.3)	39.9 (14.7)	39.9 (11.4)
Loss of consciousness (weeks)	-	2.9 (2.7)	2.8 (1.0)
GCS score	-	7.1 (3.7)	5.8 (1.6)
PTA (weeks)	-	7.1 (7.6)	79.8 (59.2)
Time post injury (months)	-	13.0 (11.7)	64.3 (50.9)
NART-R	108.6 (7.6)	102.4 (8.2)	-
WAIS-R	-	83.6 (9.9)	78.3 (12.6)

Table 10.1. Summary descriptive data on control and head-injured subjects

There were no differences between the groups in terms of age. Based on their scores on the revised NART, the severely brain injured group were of comparable premorbid

intellectual ability to the control group. In terms of injury severity, the very severe group demonstrated significantly longer periods of PTA than the severely injured group (Wilcoxon, $p < .005$) but, where it was possible to establish duration of post-trauma loss of consciousness (10 subjects overall) there was no difference between the groups. As a group, the very severely injured were significantly later post-injury than the severely injured group ($t = 3.411$, (df,21) $p < .005$). However, the severe and very severe head injury groups were functioning at a similar intellectual level as demonstrated on the WAIS-R.

Recognition memory

There were two principal aspects to the experiment. Firstly, to justify the designation of colour and verbal context as functioning as interactive and independent context information respectively. Secondly, to demonstrate the relation between item recognition, contextual information and remembered duration. Table 10.2 below provides a summary of recognition memory scores according to context for all three groups.

	Orthopaedic Controls	Severely head injured	Very severely injured
Colour context (max.17)	15.1 (1.4)	12.8 (3.3)	12.5 (3.4)
Verbal context (max.17)	10.3 (4.4)	9.5 (5.2)	1.0 (1.2)
No context (max.16)	14.4 (1.2)	13.1 (2.5)	11.3 (3.1)
Total score (max 50)	38.8 (5.7)	35.1 (8.4)	23.6 (6.9)

Table 10.2. Contextual recognition memory scores for all subjects.

As the maximum score possible varied slightly between recognition conditions, the scores were also calculated as a percentage. Figure 10.1 shows the mean scores obtained by each subject group for each condition as a percentage of maximum score. The total memory scores for controls were compared with those of all head injured subjects using a parametric ANOVA which showed that controls obtained significantly higher overall memory scores than did the head injured subjects ($F = 7.26$, $(1,32)$ $p = .01$). The severe head injury group obtained significantly higher total memory scores than the very severe injury group ($F = 9.35$ $(1,23)$ $p < .01$).

Further analyses of variance demonstrated that the controls obtained higher memory scores than the head injured subjects under recognition conditions of colour context ($F = 5.71$ $(1,31)$ $p < .05$), verbal context ($F = 5.41$ $(1,31)$ $p < .05$) and no context ($F = 5.37$ $(1,31)$ $p < .05$). The head injury groups performed similarly with respect to the colour context and no context conditions, but the very severely injured subjects performed significantly poorer than the severe head injury group ($F = 25.0$ $(1,23)$ $p < .001$). Overall therefore, the recognition memory performance of the controls was superior to that of head injured subjects, regardless of the presence or nature of context at retrieval. Head injured subjects performed similarly on most conditions, but the most severely disturbed group were clearly unable to utilise the presence of interactive context in the retrieval condition (see discussion section).

It was intended to relate total recognition memory scores with recognition scores in the presence of verbal context, colour context and the absence of context. However, by far the largest proportion of variance is derived from performance in the verbal context condition which contributes most to the overall memory score. The performance of the clinical subjects in the verbal context condition was particularly interesting. In scoring at near floor level in this condition, the very severely injured subjects appeared to be impervious to the effects of interactive context in improving recognition memory. Whether this task is particularly sensitive to frontal dysfunction is unclear as the subjects did not have discrete localised lesions and showed general intellectual difficulties.

Recognition memory scores
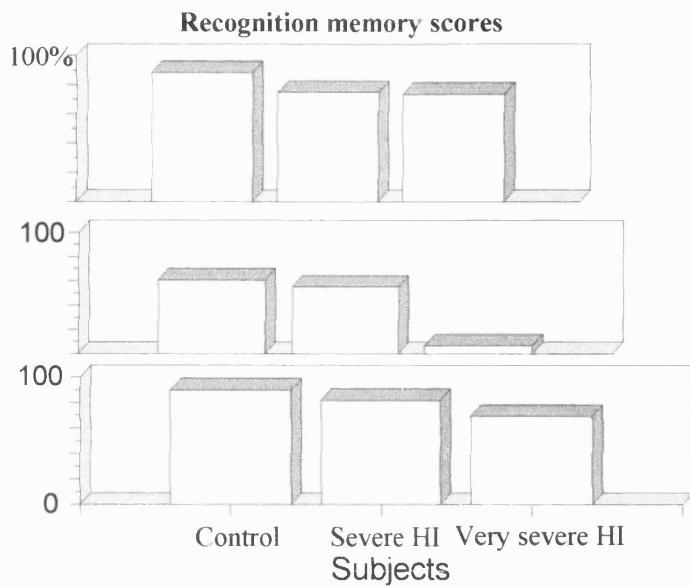
Figure 10.1 Recognition memory scores for no context (top),
verbal context (middle) and colour context (bottom) conditions

Remembered duration

The accuracy (θ) and bias or direction (ψ/t) of subjects' retrospective estimates of task duration are summarised in table 10.3 and illustrated in figure 10.2 below. Whereas the controls tended to slightly over-estimate the time interval, 18 of the 24 head injured subjects under-estimated the task duration (including the majority in the very severe group, whose mean score was distorted by outliers). Visual inspection of the mean values of theta in table 10.3 shows that the very severely head injured subjects are not only less accurate in their duration estimations but also far more variable in their responses. In contrast, the severe head injury group appear to be performing similarly to the controls. This assessment is confirmed by ANOVA which showed no significant differences between the head injured subjects as a single group and the controls ($p = .25$) whereas the severe head injury group are significantly more accurate in judging the task duration than the very severe injury group ($F = 4.46$ (1,23) $p < .05$). From a clinical perspective this striking disparity between the two head injured groups is a significant

observation which will be discussed in the next section. Interestingly, for each subjects group estimated duration was not correlated with recognition memory scores in any condition.

Remembered duration
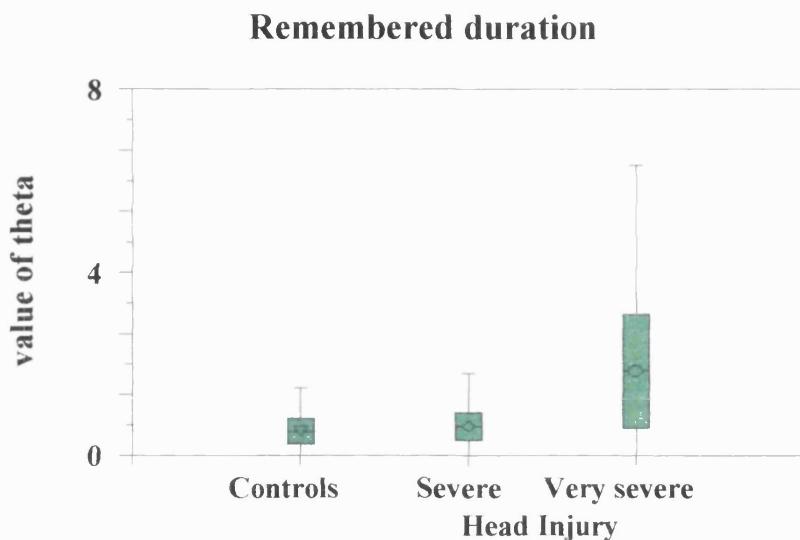
Figure 10.2. Accuracy of remembered duration of recognition memory task for orthopaedic controls, and two groups of head injured subjects.

	Orthopaedic Controls	Severely Head injured	Very severely Head injured
Task duration (secs.)	147.9 (13.2)	200.5 (70.8)	234.5 (131.8)
Mean time distortion			
(ψ/t)	1.21 (0.45)	0.69 (0.31)	1.83 (2.5)
Mean accuracy (θ)	0.53 (0.47)	0.63 (0.50)	1.85 (2.25)
Median accuracy (θ)	0.42	0.47	0.73
95% C.I.	0.21 - 0.84	0.0 - 3.02	0.0 - 3.19

Table 10.3 Accuracy and bias in remembered duration of contextual memory task

10.4 Discussion

The results showed clearly that head injury was associated with poorer recognition memory scores than obtained by non head injured control subjects. This was demonstrated for each retrieval condition, thus there was no specific effect of context which distinguished between the head injured and controls. Subjects designated as having sustained severe head injuries showed superior overall recognition memory scores compared to the very severe head injury group, but this appears to have been due to the grossly impaired performance of the latter group on the verbal context condition, effectively performing at near floor level (see table 10.2). There was no difference between the two head injury groups in any other retrieval condition.

It was proposed in section 10.2 that the presence of verbal context at the recognition judgement stage of the memory task corresponded to the provision of what Baddeley (1982) termed interactive context. If this is the case then the severely impaired recognition judgement performance of the very severe head injury group is somewhat unexpected, as encoding of associative material does not usually impede memory for item information (Hockley & Cristi,1996). However, in apparent contrast to Baddeley's (1982) predictions, performance in the verbal context condition was far from superior to recognition in the no context or the independent context condition. Whereas one would have expected that recognition judgements would be impervious to the presence of independent context, the involvement of contextual information processing in the monitoring aspects of recognition (Norman & Schacter, 1996) suggests that recognition should be facilitated by interactive context at retrieval. A plausible explanation for this result probably lies in the fact that the interactive context (the flanking letters) on recognition was a different colour (black) than it had been on presentation (red). Thus changing the colour of flanking letters from the initial presentation to the recognition stage appears to have confounded recollection as, when re-presented, the fact that all letters were printed in black afforded an alternative interpretation of the stimulus (ie. the longer word rather than the embedded word). This was especially problematic for the

most severely head-injured group who were unable to recognise stimuli in the presence of interactive context and may have been unable to implement a likelihood decision. Context-based source information is less reliably encoded with limited attention resources (Jacoby et al.,1989) and it was to be expected that this group would also show the most difficulty discriminating the target words from contextual letters in the encoding phase. Thus they may well have inadequate access to the uniqueness of the context for each stimulus word which facilitates item registration according to strength theories (Hunt & Smith,1996). This is consistent with Mayes et al. (1992) who reported that amnesics were more impaired at recognising target words in the presence of interactive context than they were without it. Interactive context did not equate with optimal recognition conditions, presumably because recognition tends to be based more on familiarity than contextual retrieval under conditions of reduced attention.

With regard to the ability to remember task duration, there was no significant difference between controls and head injured subjects overall, but the very severe head injury group showed a gross disturbance of time estimation in comparison with the severe head injury group (figure 10.2). Previous chapters have demonstrated that head injury is associated with poor concurrent monitoring of time, but this is the first study to demonstrate that retrospective temporal judgement is also severely disturbed.

Although previous studies have suggested that memory for interval duration is related to memory for events during the interval, the present results do not support this simple interpretation. Firstly, there was no overall difference in remembered time between head injured and control subjects as there was for memory performance. Second, despite the very severe head injury group showing severely impaired recognition memory in the verbal context condition and showing grossly disturbed retrospective timing, there was no significant relation between these two variables. Indeed, contrary to the contextual theory of psychological time, remembered duration did not correlate with any index of memory ability.

Of particular interest in this study is that the very severely injured subjects appear to show a qualitatively different kind of problem than do the severe injury group. This pattern of results in retrospective time estimation is entirely consistent with that shown prospectively in the story recall in chapter 5, and to a lesser extent in the complex card sorting in chapter 7. This profile of results suggests that the very severely injured subjects are displaying a qualitatively different performance in timing tasks. The implications of this were raised in chapter 3 (section 3.6) and will be elaborated in the final discussion in chapter 14. For the present, it may be surmised that those subjects with what is technically a severe head injury may nevertheless exhibit qualitatively similar, if slightly less accurate, timing ability than non brain injured controls, much as other aspects of their cognitive performance may show a degree of underfunctioning. In contrast, the consistent performance across studies of a group of individuals who have sustained an extremely severe brain injury appears to suggest that they may have an experience of time that is very different in kind from the norm rather than simply in degree.

The results of the present study therefore raise many issues with regard to theoretical accounts of psychological time, in particular to notions of remembered time. Despite evidence that memory scores were generally higher in the controls, and in spite of the differences in accuracy of remembered duration, it was not possible to demonstrate any relation between memory performance and subjective time. There was no support for the effect of any contextual manipulation, remembered duration was not influenced by the presence or the nature of contextual material, nor was it directly related to performance in the non-contextual condition or to overall memory scores. Thus it seems that the ability to remember interval duration accurately is not entirely dependent on recalling the constituent events. Other factors appear to play a role in retrospective duration as they do in prospective timing (see chapter 9). Therefore the storage size model cannot convincingly account for memory for time after brain injury, although there is some admittedly rather speculative evidence in its favour. This comes from the observation that orthopaedic subjects tended to over-estimate task duration slightly whereas both the

head-injured groups generally under-estimated task duration (though to rather different degrees). This somewhat indirect evidence in favour of a relation between memory and retrospective duration could be interpreted as indirect support for a storage model account.

However, an alternative account may be considered in terms of an internal clock. Brain injury appears to be associated with a tendency to be not just less accurate, but to underestimate task duration in retrospect (both in relation to controls and to clock time) and, significantly this is not directly related to any index of memory. If a damaged inner clock emitted fewer pulses (for example, five instead of ten pulses in a minute), clock time would be experienced as speeded up but there would be fewer sensory events by which to recall the interval duration, hence it would be underestimated. Hence internal clock theories can explain retrospective time distortions, but there should still be a predictable relation between event order and duration, although in chapter 4 no such relationship was demonstrated. Further discussion concerning the inadequacies of contemporary theories of psychological time is deferred until chapter 14. The remaining empirical chapters are concerned with elucidating those aspects of psychological time which such current theoretical approaches have neglected, namely executive skills and, firstly, semantic memory.

Chapter 11

Memory and Psychological Time:
Semantic memory and the ability to tell the time

11.1 The ability to tell the time

Throughout previous chapters experimental studies have demonstrated that the subjective experience of time may be adversely affected after brain injury. These difficulties may depend on injury severity but can follow diffuse or more focal pathology and, it was argued in chapter 2, such deficits can produce more chronic disabling difficulties which have significant social and functional consequences. Of course, the weight of evidence showing that disturbances in time estimation can follow severe brain injury does not mean that afflicted individuals have no concept of time, but simply that there may be quantitative or perhaps qualitative differences in their experience of time. The ability to monitor temporal passage and estimate duration is only one of many facets of the rather nebulous construct of psychological time. Another important aspect of the concept of time is utilised in the ability to tell the time or perform what will be called 'clock reading' tasks. Being able to tell the time involves understanding the relation between a standard form of temporal notation, such as the clock, and the broader notion of time and temporal passage to which it corresponds. This entails a significant semantic memory component as the skill is a learned one requiring familiarity with conventional representations of time and its subdivisions. As discussed in chapter 3, section 3.4, knowledge about time has both numerical and linguistic aspects as well as specific properties attributable to the conventional manner in which time is conceived and measured. It seems plausible then to assume a priori that there is an important semantic memory contribution to the construct of psychological time.

Further support for a semantic element to this process comes from clinical observation that distortions of temporal experience and temporal reasoning may occur in the presence of spared ability to tell the time at any given moment and to retain some temporal facts (for example, chapter 10). Disoriented patients may be able to read their wrist-watch or a wall-clock quite accurately, and compliance with rehabilitation regimes can be facilitated by the presence of a conspicuous timing device. Moreover, some dementing patients seem to retain knowledge about numbers and can tell the time despite gross semantic memory impairment (Hodges et al., 1992). This raises the possibility that there is something about conventional representations of time which is particularly insensitive to organic brain damage.

Despite these conjectures, the ability to tell the time has yet to be investigated systematically in clinical groups. Kartsounis and Crewes (1994) reported a transitory time-reading difficulty in a 57 year-old man with a posterior cerebral artery infarction. This patient had problems telling the time from a real or imagined clock face even though he could report the positions of the hands accurately and could set clock hands to specific times on instruction. He also had significant visual perceptual problems and showed visuo-spatial neglect, in the light of which his poor performance on time transcoding with visual stimuli is difficult to establish as a selective deficit. However, his perceptual skills were reported to be satisfactory with non-degraded stimuli, and he showed no apparent neglect on clock-related tasks. His internal representations of clocks were also said to be adequate, given that he could describe their appearance from memory. Kartsounis and Crewes explain his impairment in terms of defective retrieval of facts about clocks and time. Unfortunately they offer no evidence that such facts are preserved or suggest what they may constitute. The term *Horologagnosia*, by which the authors describe this impairment, is slightly misleading given the patient's perceptual

problems, and should be reserved for cases of impaired knowledge about clocks in the absence of gross apperceptive disturbance. Interestingly, this patient also showed difficulties performing addition and subtraction with two-digit numbers (Kartsounis, personal communication) suggesting that he may have had concomitant numerical processing deficits. Clearly, more systematic study of the ability to tell the time is required in order to consider the extent to which this skill is self-contained (Tuokko et al.,1994).

In attempting to investigate this further an important preliminary step is to consider the adequacy of current accounts of the processes involved in being able to tell the time. The absence of any such explicit framework necessitates that some initial model is established, even if only on somewhat intuitive grounds. This will then permit more systematic investigation of the components of the model. On this basis a provisional framework is proposed for characterising cognitive processes involved in telling the time. First, it is assumed that digital/analogue clock reading and time production requires the integrity of basic visual and numerical skills, in addition to adequate working memory and motor functions. It may also be presumed that analogue and digital forms of time representation differ in their dependence on particular general-purpose cognitive processes (eg. perceptual skills) while sharing specific temporal properties in so far as they are associated with an abstract concept of time. Thus it is proposed that telling the time is an intermediate-level process incorporating abstract semantic representation of time and modular cognitive skills (number processing. calculation, perception etc.). This provisional model is illustrated in figure 11.1 below.

Following the same approach taken in previous chapters, the principal method of addressing this issue here is to relate time-telling performance to the status of other skills which it might be presumed to entail. Intuitively one would expect that telling the time

involved visual and numerical abilities (both of which were compromised in Kartsounis and Crewes' patient) as well as some more abstract semantic representation of time. It follows that time-telling can be considered a separable process to the extent that it may be impaired in the absence of dysfunction in other cognitive domains. Conversely, preservation of the ability to tell the time in the context of other deficits (perceptual, numerical, semantic) suggests that it is not wholly subsumed by the processes noted to be impaired.

Visual presentation   *Auditory presentation*

ANALOGUE TIME REPRESENTATION   DIGITAL TIME REPRESENTATION

ABSTRACT CONCEPT OF TIME

Written production   *Spoken production*
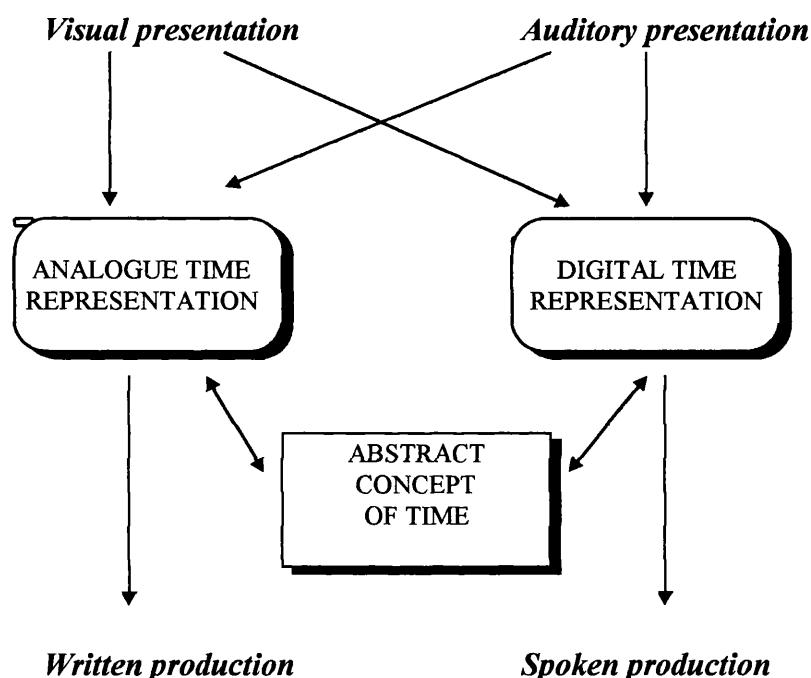
Figure 11.1. Schematic model of processes involved in telling the time.

Clock time may be understood in digital or analogue form, each of which can operate independently of the other. The skills of analogue time reading is generally acquired much earlier. These processes depend equally on adequate sensory functioning but differ in terms of their numerical and visuo-spatial demands. Comprehension and production of spoken times assumes adequate auditory-verbal short-term memory and

speech production skills. Written digital or analogue time comprehension/production requires visuo-spatial and grapheme-motor functions. Number processing abilities are essential but not sufficient for all forms of time processing. In adults both time formats are associated with an abstract concept of time although this may not be necessary to the task of clock reading.

11.1 (i) Visual perceptual skills and telling the time

Adults and children employ spatial metaphors in describing and depicting their mental representations of time (Friedman,1990). For example, in a now classic experiment Paivio (1978) showed that the time taken to compare the angles subtended by imagined clock hands (representing digitally presented times) depended on the magnitude of the difference between the times presented. This task has also been shown to be sensitive to unilateral neglect (Grossi et al.,1989), as is clock-drawing (Wilson et al.,1987; Ishiai et al.,1993). It is therefore likely that clock reading skills will also be affected by apperceptive deficits such as visual disorientation, poor line orientation, left/right disorientation and visuo-spatial neglect. Certainly, Kartsounis and Crewes' (1994) patient had time-telling difficulties with visual stimuli which could have been related to his visuo-spatial problems.

11.1 (ii) Number processing and telling the time

Understanding the relevance of number knowledge in time reading requires an appreciation of the mechanisms of numerical processing. For example, a 59 year old lady exhibited a cross-modality impairment for dealing with numbers above four with preserved comprehension of lower numbers, following a left middle cerebral artery stroke (Cipolotti et al.,1991). As a result she was unable to tell the time, dial a telephone number, or do simple calculations. This extended to a deficit in temporal facts (eg how many days there are in a week, her age, etc.) although she performed normally on semantic memory tasks. Her inability to tell the time can therefore be related to loss of

knowledge about a particular subset of numbers. Of course, the function of numerical processing skills in telling the time may depend on whether the clock is represented in digital or analogue format. Although calculation may utilise abstract digital concepts of number (Todd et al.,1987), clocks have been predominantly analogue devices until recently and thus clock reading may also depend crucially on non-arithmetical processes.

Summary

In summary, the ability to tell the time requires a store of semantic knowledge and adequate numerical and perceptual skills. Various clinical signs suggest that this skill may be resilient to some forms of brain damage, even in the presence of disturbances of temporal experience. Selective deficits in number processing have been documented relating to disruption to the individual *lexical* elements in a number (McCloskey & Caramazza,1987) and the *syntactic* relations among elements (Noel & Seron, 1993; Cipolotti et al. 1994). If telling the time were a specifically numerical task, one should observe similar patterns of dissociation on time-telling tasks. However, numerical processing is subject to attentional influences (Cohen & Dehaene,1991) and a numerically-based time-telling skill might also draw upon visual skills and be affected by perceptual deficits. Therefore the present study was primarily concerned with the relevance of visual and numerical processing to time comprehension. In addition however, the notion of an abstract concept of time was also to be examined in the light of anecdotal reports of allegedly selective deficits such as time agnosia (Davidson,1941) and horologagnosia (Kartsounis & Crewes,1994) which suggest that there may be a critical semantic memory contribution to the ability to tell the time. These issues are explored in the following investigations. Each component of the model will now be examined in the light of the empirical evidence generated by the four cases presented.

11.2 Investigating the ability to tell the time

The present study reports preliminary investigations with four patients, all of whom were reported by clinical staff to have some difficulties with being able to tell the time. Two of the subjects had suffered generalised brain damage, a third had left hemisphere pathology and the fourth presented with a right hemisphere lesion. Although two individuals were also poorly oriented for time, which precludes demonstrating any general dissociation of time-related abilities, it is their understanding of conventional representations of time compared with their number processing and visual perceptual skills which is of primary interest. The participants were assessed in terms of an influential model of numerical processing (McCloskey et al. 1991) which proposes separate lexical and syntactic aspects of number processing, each shared between spoken and written production modalities for each form of number representation (Sokol & McCloskey,1988). The same framework was used to investigate comprehension and production processes in time-telling tasks to assess the extent to which the tasks required intact numerical processing, and to consider the utility of this model beyond arithmetical skills. Transcoding tasks requiring translation of numbers from one format (arabic/verbal) and one medium (spoken/written) into another have been widely used to isolate specific deficits, even within multiple impairments (Deloche & Seron, 1987; Macaruso et al.1993). The same strategy was employed in the present study with clock times, requiring the translation of times from an analogue or digital format across modalities (visual/auditory).

11.2 (i) Experimental Investigations

In addition to a standardised routine cognitive assessment each patient was administered a series of specialised neuropsychological tests. This included the John Hopkins Dyscalculia Battery (M. McCloskey, unpublished). This test is based on an explicit model of numerical processing and calculation mechanisms (McCloskey et al.,1991X)

and incorporates assessment of magnitude comparison and calculation skills as well as a range of arabic and written number transcoding tasks. In addition, a number of tasks sensitive to visual perceptual deficits were selected from the Visual Object and Space Perception Battery (VOSP), (Warrington & James,1991) and the Birmingham Object Recognition Battery (BORB), (Riddoch & Humphreys,1993), to which were added two further orientation tasks (Benton et al,1983). The exhaustive list of subtests used included in appendix B.1.

Temporal Transcoding Tasks

In addition to these more standard neuropsychological measures, a series a time-transcoding tasks were also administered. These were divided into tasks necessitating translation between auditory (spoken) and visual modalities and those requiring transcoding from one form of temporal representation to another (so-called cross-temporal transcoding). Thus in the visual mode the times to be transcoded were presented or responded to either in digital form as written numerals (eg. 2:10) or were displayed on a large analogue clock face. For this purpose the clock apparatus from the Behavioural Inattention Battery (Wilson et al.,1987) was particularly appropriate. In the spoken presentation mode the times were read out in either analogue form (" ten past two") or digital form ("two-ten") and a similar response was demanded of the patients. In total there were twelve transcoding tasks, each comprising twenty items (see table 11.1). This permitted analysis of performance in terms of the modality of presentation and response, and the nature of the time representation.

Essentially, these time transcoding tasks were designed to utilise many of the same component skills required by the numerical transcoding tasks in the dyscalculia battery and the perceptual tests, with the important additional factor that they also required an appreciation of temporal representation. Thus satisfactory performance on the numerical

and visual perceptual tasks would not be sufficient to complete the time transcoding tasks adequately. However, a deficit in the component numerical or perceptual skills would be expected to have a fairly predictable outcome on the results. The results of the time transcoding tasks were therefore compared with patients' performance on numerical and perceptual tests to explore the possible dependence of time reading on these processes.

Cross temporal transcoding	Cross modality transcoding
1. Visual (written) digital to visual analogue	5. Visual analogue to spoken analogue
2. Visual analogue to visual (written) digital	6. Spoken analogue to visual analogue
3. Spoken digital to spoken analogue	7. Spoken digital to visual digital
4. Spoken analogue to spoken digital	8. Visual digital to spoken digital

Mixed cross modality, cross - coding
9. Spoken digital to visual analogue
10. Visual analogue to spoken digital
11. Spoken analogue to visual (written) digital
12. Visual (written) digital to spoken analogue

Table 11.1 Summary of time transcoding tasks

11.2 (ii) Results

The results are presented for all four subjects and then each one is discussed separately. All subjects completed items from standardised visual perceptual tests, the dyscalculia battery, and temporal transcoding tasks. The scores obtained on perceptual assessment are shown in table11.2. below

Task	VF	DC	AS	DG
Position discrimination (20)	19	-	19	10 *
Number location (10)	9	6	6	8
Cube analysis (10)	9	-	7	3 *
Line orientation (30)	17*	-	16*	8 *
Vertical length-match (30)	25	23*	26	25
Horizontal length match (30)	26	26	28	21 *
Orientation match (30)	19*	23	26	20
Easy object decision (32)	30	28	30	29
Hard object decision (32)	20*	-	27	24 *
Silhouette object decision (30)	-	-	-	14
Minimal feature matching (25)	-	-	-	24
Foreshortened view matching (25)	-	-	-	23
Copying	good	-	fair	poor
Drawing from memory	good	-	fair	fair

Table 11.2 Performance of subjects on spatial and visual perceptual tasks

(* denotes an impaired score, > 2 SD.s below available norms)

The results from the dyscalculia battery are summarised in table 11.3 below. Although only total subtest scores are shown, most tasks involved processing of small numbers (ie. < 3 digits) and larger numbers in equal proportions. It is worthwhile considering performance on the two classes of number separately, not least because satisfactory ability to process two-digit numbers would seem a priori to be sufficient to cope with the numerical demands of telling the time. Results from the dyscalculia battery were

analysed using the chi-squared statistic (Siegal & Castellan,1988) to examine the distribution of scores across transcoding tasks.

The time transcoding tasks were scored in terms of overall number of errors and the type of error. The classification of errors as lexical or syntactic is less clear for written numbers than arabic numerals. Likewise there are difficulties in maintaining a consistent analysis for time-transcoding tasks. For example, a lexical error in digital time production (eg. *12:10* instead of 10:10) is a spatially based error on visual analogue production which may have nothing to do with the elements in a number which characterises lexical errors in arabic numeral production. Therefore a provisional framework was developed in which visual analogue errors were considered separately from lexical errors in digital and spoken conditions. Visual analogue errors were either transpositions of the clock hands (eg. ten past eight instead of twenty to two) or inaccurate placement of individual hands beyond a two minute cut-off criterion (a displacement of 12°). Syntactic errors were of three types: minute reversals (*20* for 02), hour reversals (*10:12* for 12;10) and relational errors (twenty-*past*-six instead of twenty-*to*-six). Performance across twelve time transcoding tasks was analysed for modality and stimulus representation effects. Table 11.4 overleaf shows the results for spoken and visual comprehension and production of clock times.

Task	VF	DC	AS	DG
Magnitude comparison				
Arabic (20)	19	20	20	20
Spoken verbal (20)	20	20	16	20
Written verbal (20)	18	18	11	20
Transcoding				
Arabic - spoken verbal (20)	20	19	12	20
Spoken verbal - written verbal (20)	20	20	0	20
Spoken verbal - arabic (20)	20	12	9	20
Arabic - written verbal (20)	19	19	0	20
Written verbal - spoken verbal (20)	20	18	9	20
Written verbal - arabic (20)	19	10	9	20
Written arithmetic				
Function verification (10)	10	7	3	10
Addition (20)	17	-	-	-
Subtraction (20)	12	-	-	-
Multiplication (20)	4	-	-	-
Mental arithmetic				
Function verification (25)	23	17	15	25
Addition (10)	9	-	-	-
Subtraction (10)	8	-	-	-
Multiplication (10)	4	-	-	-

Table 11.3 Summary of performance on number processing tasks

from John Hopkins Dyscalculia Battery.

Transcoding task	VF	DC	AS	DG
Modality				
Spoken - spoken	11/40	15/35	0/40	40/40
Visual - visual	11/40	19/30	22/40	29/40
Spoken - visual	49/80	52/64	37/80	70/80
Visual -spoken	62/80	64/80	18/80	67/80
Material				
Analogue - analogue	34/40	31/34	16/40	33/40
Digital - digital	40/40	38/40	20/40	40/40
Analogue - digital	19/80	17/55	16/80	69/80
Digital - analogue	40/80	61/80	25/80	64/40

Table 11.4 Number of correct responses in spoken and visual time transcoding tasks.

(Note: some subjects refused to complete all items in a task)

11.2 (iii) Case analysis

In this section the results are detailed from each subject in turn and discussed in terms of their respective neuropsychological deficits.

Case VF

VF is a 44 year-old lady who sustained hypoxic brain damage following a myocardial infarct on 3rd February, 1994. She was resuscitated on the way to hospital, ventilated for five days and transferred from ITU after two weeks. Despite a good physical recovery she presented with widespread cognitive-

behavioural difficulties and proved a management problem on the hospital ward. She was transferred to a behavioural rehabilitation unit on 1st March, 1994. Initial neuropsychological assessment (3.3.94) showed marked disorientation and severe intellectual impairment (regression-estimated Verbal IQ=62, Performance IQ=71, Full scale IQ=62). She had significant short-term memory difficulties for digits and sentences, impaired recognition memory for words and faces, poor autobiographical recall, and mild anomia with some semantic paraphrasias. Her proverb interpretations were very concrete and she had difficulties learning a unimanual sequence of gestures, suggesting some frontal lobe dysfunction.

Visual perceptual and numerical skills

VF has good copying skills and length discrimination ability, but showed difficulties on two line orientation tasks (scores on both tasks being < 5 % of published norms) and the harder Object Decision task. This suggests that VF has some spatial orientation problems and difficulties accessing stored object knowledge from perceptually realistic stimuli, though her drawing from memory and score on the "easy" object decision were quite adequate. VF completed the magnitude comparison tasks adequately, making one error on arabic comparisons (426 vs. 246) and two errors on written number comparisons (914 vs. 920; 15,200 vs. 40,000). She shows good numerical transcoding skills across all forms of number representation ($\chi^2 = 4.031$ $p>0.05$), making only 2/120 transcoding errors (writing 50,087 as "fifty thousand and eighty thousand" and writing the letter 4 in response to the written word "fourteen"). Her comprehension of arithmetic symbols was good but she showed poor written and spoken multiplication (mean = 27%) in the context of adequate addition and subtraction skills (mean = 77 %), the latter being assessed as low average on a graded calculation test (Jackson & Warrington, 1986). The results suggest that VF has preserved number processing skills and calculation procedures with impairment of arithmetic fact retrieval.

Time transcoding

The time transcoding results for all subjects are shown in table 11.4 above. In addition, for ease of comprehension, the summary results from each subject will be tabulated separately in the discussion of individual cases. For VF, and all later cases, the time transcoding data were subject to non-parametric analysis for association (Siegal & Castellan,1988), the hypothesis being that differences in the relative frequency of correct responses on transcoding tasks would exceed the variability expected by chance. Subsequent analysis of differences in mean scores across tasks was by t-test unless otherwise indicated. Table 11.5 below summarises VF's temporal transcoding performance in terms of the modality of stimulus presentation and response. Yates corrected chi-square values indicated that the distribution of scores departed significantly from chance (χ^2 = 42.2 (df,1) p<0.001). A review of table 11.5 suggests that VF performed significantly better on cross-modality than within-modality transcodings as she scored only 28% correct on spoken-spoken and visual-visual tasks compared to 78% and 61% on visual-spoken and spoken-visual transcodings respectively (χ^2 .= 60.3 (df,1) p <.001). She showed a trend (p < .1) towards higher scores with visually presented material for both time comprehension and production. Her performance was superior when transforming spoken times to visual, and vice versa (regardless of whether this also entailed a translation between different representations of time), compared to transcodings which involved translations within a modality which always did involve translation between analogue and digital forms of time.

	Spoken output	Visual output	*Total*
Spoken input	11/40 (28 %)	49/80 (61%)	*60/120 (50%)*
Visual input	62/80 (78%)	11/40 (28%)	*73/120 (61%)*
Total	*73/120 (61%)*	*60/120 (50%)*	

Table 11.5 VF: summary of temporal transcoding according to modality

Table 11.6 shows VF's performance as a function of the type of temporal representation involved. A Yates corrected chi-square analysis demonstrated that the distribution of scores was a significantly above chance (χ^2 = 49.4, (df,1) p<.001). Her scores on items involving analogue comprehension were poorer than those involving comprehension of digital times (χ^2 = 12.3 (df,1) p <.001), but there was no difference in her ability to reproduce analogue and digital times. Further analysis demonstrated that VF had markedly more problems transcoding analogue to digital times and vice versa than within the same time format across modalities (χ^2 = 91.8 (df,1) p <.001). Moreover, regarding the problematic cross-code translations, her ability to transcode from analogue to digital format was notably inferior to her ability to translate from digital to analogue (χ^2 = 11.8 (df,1) p <.001).

VF's visual perceptual difficulties appear to have no bearing on these results as she shows marginally superior visual comprehension (73/120) over spoken comprehension (60/120), and her production of visual analogue times (64/120) was certainly no worse

than her visual digital responses (56/120). There was likewise no suggestion of a perceptual contribution to VF's ability to process digital representations of time, as she was at least as competent with visual digital than spoken digital times (74/120 vs. 65/120).

	Analogue output	Digital output	*Total*
Analogue input	34/40 (85%)	19/80 (24%)	*53/120 (44%)*
Digital input	40/80 (50%)	40/40 (100%)	*80/120 (67%)*
Total	*74/120 (62%)*	*59/120 (49%)*	

Table 11.6 VF: summary of transcoding performance according to temporal code

Overall, VF had fairly generalised problems in transcoding forms of time. She shows clear tendencies to perform better within a temporal code than when transcoding between temporal representations. VF performed better on inter-modality transcodings (where the temporal form remains constant) than on intra-modality translations which is entirely consistent with her propensity to show greater facility with intra-code manipulations than transcodings between temporal forms. Additionally, VF also seems to show greater comprehension of visually-represented times than spoken times. It may be speculated that VF has particular difficulty in analogue time comprehension, a contention which is supported statistically by evidence that her ability to transcode from analogue to digital times (as opposed to digital to analogue) is especially poor ($\chi^2 = 11.8$, (df,1) $p < 0.001$).

If VF's difficulties cannot be entirely accounted for in terms of deficiencies in component numerical and perceptual skills, then an argument can be made that additional, time-specific impairments could be involved. Considering her generally competent performance on the John Hopkins dyscalculia battery, VF's results were obtained in the absence of evidence of specific numerical processing deficits. Her auditory-verbal short-term memory problems are unlikely to have contributed to weaker performance on comprehension of spoken times, as no adverse effect was evident on spoken number transcoding tasks on the dyscalculia battery. VF's visual perceptual problems also appear to have had a negligible effect on her ability to process visually represented clock times. These findings raise the suggestion that representations of time cannot be understood solely as the integration of more general visuo-spatial and numerical processing functions.

Case DC

DC is a 32 year-old right-handed man who sustained an extremely severe head injury in a road traffic accident in April, 1994. A CT scan showed evidence of a left cerebellar skull fracture, gross oedema of the right hemisphere and frontal contusions. His rehabilitation was hampered by prolonged PTA which lasted approximately 12 months. At the time of assessment (5.5.95) he was resident in a community rehabilitation centre. Neuropsychological assessment demonstrated borderline Verbal skills (VIQ=72) and impaired nonverbal skills (PIQ=66) on the WAIS-R and Raven's (1956) Coloured Progressive Matrices. He was poorly oriented for both time and place (he could not recall the date, month or year). He had short term memory and episodic memory difficulties and performed at chance level on a shortened verbal recognition memory test (14/25). His memory for autobiographical information was rather better preserved, although he had a marked retrograde amnesia for events. He showed signs of prefrontal dysfunction on several tasks. Behaviourally, he was prone to repetitive and occasional stereotypical threats of aggression.

Visual perceptual and numerical skills

DC shows some difficulties discriminating length in a vertical plane in the context of satisfactory length matching of horizontal lines and orientation matching. He made only 2/60 errors on magnitude comparison tasks, both on written verbal numbers (920 vs. 914; 2100 vs. 2080). On transcoding tasks he showed problems comprehending written numbers (50%) although he performed well on tasks requiring written number production (97.5 %). His arabic number production errors tended to be of a syntactic nature (eg. 11,038 written as 11,000 38; 480 written as 408) although there were some instances of lexical or mixed errors (eg. 80 written as 8; 7,851 written as 7,000 8,21). DC also had significant difficulties producing arabic numerals (36 %), despite good scores on arabic number comprehension tasks (95 %). Again, most of his errors were of a syntactical nature (eg.30,694 written as 30 600 94; 680 written as 600 80) suggesting poor understanding of relations among elements in a number. These relative deficits were only evident on numbers greater than two digits, there was no difference in transcoding arabic and written forms of smaller numbers ($\chi^2 = 2.582, p > 0.1$). He also showed some difficulties comprehending arithmetical operation symbols in written (7/10) and spoken form (17/25), but refused to carry out the calculation tasks.

In summary, DC demonstrated particular difficulties with written number comprehension and arabic numeral production, with preservation of number comprehension on magnitude comparison tasks. However these difficulties were not apparent for numbers with less than three digits.

Time transcoding

Due to his attentional limitations and propensity to agitation in the face of repeated demands, DC did not complete all the time transcoding tasks. However sufficient data

were obtained to permit inferential analysis and make meaningful comparisons with the other patients. Summary results are shown in tables below 11.7 and 11.8 below.

The initial test for association demonstrates a significant effect across the groups (χ^2 = 27.802, (df,1) p < 0.001). He produced higher scores with visual rather than spoken material, for both time comprehension (χ^2 = 7.9 (df,1) p < .01) and production (χ^2 = 17.0 (df,1) p < .001). When the scores for the two within-modality tasks (spoken-spoken and visual-visual) are compared with those obtained from cross-modality tasks (spoken-visual and visual-spoken) DC appears to perform much better (χ^2 = 33.9 (df,1) p < .001) on cross modality than within modality transcodings (81% vs. 49%). Like VF, DC shows a tendency to superior performance when translating between auditory and visual forms of either digital or analogue times, compared to his ability to transcode analogue and digital times within the same modality.

	Spoken output	Visual output	*Total*
Spoken input	30/70 (43%)	52/64 (81%)	82/134 (61%)
Visual input	64/80 (80%)	19/30 (63%)	83/110 (75%)
Total	*94/150 (63%)*	*71/94 (76%)*	

Table 11.7 DC: summary of temporal transcoding according to modality

Within a modality, when nature of the temporal code is ignored, he shows reasonably competent performance separately for spoken input (67/99), visual input (83/110) spoken output (70/105) and visual output (83/110). Thus, rather like VF, DC's problems seem to

affect the transcoding process, his performance being primarily determined by the nature of the numerical representation. The results are displayed in terms of temporal representation in table 11.8 below.

Chi-square analysis shows that the distribution of scores deviates significantly from that expected by chance alone ($\chi^2 = 61.081$, (df,1) $p < .001$). With regard to any differences in processing different temporal codes, DC is especially poor in translating between temporal codes relative to cross-modality translations within codes ($\chi^2 = 44.2$ (df,1) $p < .001$). This is consistent with his inferior performance on within-modality transcoding compered to cross-modality transcoding. Furthermore, his comprehension of digital times surpasses that of analogue times ($\chi^2 = 24.1$ (df,1) $p < .001$) but his ability to reproduce analogue times is poorer than his digital time production ($\chi^2 = 14.5$ (df,1) $p < .001$). Consequently, DC was particularly poor in translating from analogue to digital format, rather than vice versa, ($\chi^2 = 31.2$ (df,1) $p < .001$).

	Analogue output	Digital output	Total
Analogue input	31/34 (91%)	17/55 (31%)	*48/89 (54%)*
Digital input	61/80 (76%)	38/40 (95%)	*99/120 (83%)*
Total	*92/114 (81%)*	*55/95 (58%)*	

Table 11.8 DC: summary of transcoding performance according to temporal code

There does not appear to be any significant contribution to this pattern of performance in terms of DC's known neuropsychological deficits. For example, his perceptual problem

of discriminating vertical line length does not seem to have adversely affected his understanding or reproduction of analogue times on a clock face. Likewise, despite his previously documented arabic number production difficulties for numbers >2 digits his production of digital times is significantly better than his ability to reproduce times in analogue format.

The results from DC can now be added to those obtained from VF, whose data raised the suggestion that time transcoding problems were not entirely explicable in terms of constituent numerical and perceptual processes. This contention is given added support by the profile of results from DC, which is very much in keeping with VF's performance. Thus, both showed clearly superior performance when required to translate between auditory and visual modalities than when performing within-modality manipulations. Similarly, both subjects showed problems in transcoding between digital and analogue representations of time. The similarities between these two subjects are important because, although both had generalised brain damage, they exhibited different mechanisms and patterns of brain injury (hypoxic versus acceleration) and they showed some differences in neuropsychological functioning. VF had preserved number processing skills but showed some spatial orientation problems. In contrast, DC showed a range of impairments of numerical processing but little in the way of perceptual disturbance except for some difficulty in discriminating vertical line length. As these deficits affect different aspects of the likely constituent numerical and perceptual components of time telling, they might have been expected to impinge differently on the subjects' performance on time transcoding tasks. The fact that they did not, and the fact that DC and VF performed remarkably similarly, adds weight to the suggestion that telling the time involves time-specific processes. To examine this hypothesis more thoroughly, it is necessary to investigate the performance of individuals who show either

fairly specific perceptual problems or relatively selective language/numerical processing disorders. This is the rationale for the analysis of the final two cases.

Case AS

AS is a 61 year-old man, who suffered a small left parietal infarct in the territory of the left middle cerebral artery, in January,1994. He made good progress and was discharged to a community rehabilitation unit after six weeks. Neuropsychological assessment showed impaired Verbal skills (IQ=59) and borderline performance skills (IQ=78) on a full WAIS-R (Full Scale IQ=67). His recent memory for both verbal and visual information was poor. His verbal comprehension was weak and he had severe expressive speech problems. He was able to repeat correctly only 20/60 high frequency single words (1-3 syllables). His spontaneous speech was similarly limited. He scored 20/26 writing alphabet letters to dictation and his written and oral spelling was severely impaired. He also showed difficulty naming, recognising and writing numbers.

Visual perceptual and numerical skills

AS shows satisfactory discrimination of length, orientation, relative position and stimulus enumeration together with adequate access to stored knowledge about objects. His drawing and copying skills are compromised by motor problems but are perceptually satisfactory. These results are in keeping with his known left hemisphere pathology and indicate preservation of visual perceptual skills. Consistent with his lesion he also shows significant difficulties in transcoding number representations, particularly when required to write number names ($\chi^2 = 48.72$, $p < .001$). He is virtually unable to transcode any representations of the longer three-digit numbers, the majority of correct responses (34/37) being obtained with one or two digit numbers. Separate analysis of his performance with these smaller stimuli confirms that he shows a severe written number production deficit in the presence of general number processing difficulties ($\chi^2 = 39.66$,

$p < .001$). This is consistent with his poor written output and indicates a general dysgraphic disorder.

His magnitude comparison skills are also consistent with this explanation in that he shows specific comprehension difficulties with written verbal representations of large numbers (2/10) compared with smaller numerals (9/10), ($\chi^2 = 11.98$, $p < .01$). His impaired calculation skills may be undermined by poor operation symbol comprehension, especially for written forms.

Time transcoding

The results of time transcoding tasks for AS are shown in table 11.9 below according to stimulus modality. A chi-square analysis demonstrates a significant effect overall in the distribution of scores ($\chi^2 = 39.76$ (df,1) $p < .001$). However, in contrast to the pattern of results obtained from the two previous cases, AS performs much worse on cross-modality than are within-modality translations ($\chi^2 = 27.70$ (df,1) $p < .001$). While there is no significant modality difference between his comprehension of times, he is, naturally enough, much poorer in spoken production than visual production (($\chi^2 = 32.10$ (df,1) $p < .001$) This is because AS has difficulties with just about any task involving speech production, scoring a total of 18/120 (15%) for items requiring a spoken response. This is despite evidence from the dyscalculia battery of good spoken production of small numbers from both written verbal (9/10) and visual arabic (8/10) formats, suggesting that digital times are at least equivalent to 3-4 digit numbers. Therefore in summary, AS shows general problems in transcoding tasks which involve the mediation of speech.

	Spoken output	Visual output	*Total*
Spoken input	0/40 (0%)	37/80 (46%)	37/120 (31%)
Visual input	18/80 (23%)	22/40 (55%)	40/120 (33%)
Total	*18/120 (15%)*	*59/120 (49%)*	

Table 11.9 AS: summary of temporal transcoding according to modality

Table 11.10 below shows the results in terms of the kind of temporal representation involved . A chi-square analysis revealed that the distribution of scores was significant (χ^2 = 18.2 (df,1) p < .001). Manipulations within the same temporal code (ie. analogue-analogue, digital-digital) are performed significantly better than transcodings between analogue and digital formats (χ^2 = 34.8 (df,1) p < .001) which raises an interesting suggestion that AS , like VF and DC, may have particular problems in translating between codes, quite independently in this case of the problems caused by his dysphasia and number processing impairment.

Somewhat counter-intuitively, the accuracy of his digital to digital translations (50%) exceeds that of all other manipulations. Given evidence on the John Hopkins battery that he had severe transcoding problems for numbers greater than two digits, his time transcoding performance involving digital times is relatively well preserved (see table 11.10). Errors of commission showed mostly lexical mistakes in written and spoken digital production (eg. responding 4:36 for 4:07) but his production of digital times was no different from his analogue time production.

	Analogue output	Digital output	*Total*
Analogue input	16/40 (40%)	16/80 (20%)	*32/120 (27%)*
Digital input	25/80 (31%)	20/40 (50%)	*45/120 (38%)*
Total	*41/120 (34%)*	*36/120 (30%)*	

Table 11.10 AS: summary of transcoding performance according to temporal code

In contrast to VF and DC, AS shows no significant difference between analogue and digital representations of time in terms of comprehension or production, although his understanding of digital times (38%) is marginally superior to his comprehension of analogue times ($p < .1$ on a chi-square test). Furthermore, unlike DC and VF, AS has no greater problems with analogue-digital than digital analogue transcoding.

In summary, AS has pervasive deficits of language and number processing which have undermined his performance on many time-transcoding tasks. However, he still showed greater facility for within-code temporal manipulations (analogue-analogue and digital-digital) and was surprisingly adept at manipulating digital representations of time relative to other arabic number tasks. These results are difficult to account for entirely in terms of his general neuropsychological profile, and it seems plausible to consider whether numbers which represent time may be endowed with additional properties associated with their temporal meaning. Further discussion of this matter is left until after the final case is presented.

Case DG

DG is a 60-year-old man who suffered an acute myocardial infarction and subsequent stroke in January,1994, causing a large right hemisphere occipito-parietal lesion with right internal capsule haemorrhage. He made satisfactory progress and was discharged home after three weeks attending out-patient rehabilitation. Neuropsychological assessment in March, 1994 demonstrated average verbal intellectual skills (VIQ=103) and borderline non-verbal abilities (PIQ=74). He was noted to have some difficulties in copying line drawings which suggested visuo-spatial problems though he had no significant visual neglect (scoring 138/146 on the six conventional tasks of the Behavioural Inattention Test).

Visual perceptual and numerical skills

As illustrated in table 11.1 DG performed poorly on pre-categorical tasks involving discrimination of length, orientation and relative position. By contrast, his knowledge of object appearance was relatively preserved, his drawing from memory was superior to his copying, and he could access structural descriptive information from minimal features and foreshortened views (although his performance on object decision tasks was generally weak). On the dyscalculia battery he completed number magnitude comparison and numerical transcoding tasks satisfactorily and showed good arithmetic function comprehension for written and spoken symbols.

Time transcoding

DG's performance on time transcoding tasks according to modality of stimulus presentation and response is shown in table 11.11. In view of his orientation, length and spatial position impairment it is perhaps surprising that his general level of performance was as high as it was. Nevertheless chi-square analysis showed that the distribution of scores departed significantly from that expected by chance (χ^2 = 18.2, (df,1) $p < .001$). Although his scores were equivalent for visual input (96/120) and visual output (99/120), his comprehension of spoken times exceeded that of visually presented times (χ^2 = 6.7

(df,1) $p < .01$) but there were no modality differences in time production. Hence his time-transcoding with visual stimuli was notably poorer than his performance with spoken material ($\chi^2 = 13.0$ (df,1) $p < .01$). To the extent that his performance shows areas of relative weakness, these are entirely explicable in terms of DG's known perceptual impairment.

	Spoken output	Visual output	*Total*
Spoken input	40/40 (100%)	70/80 (88%)	*110/120 (92%)*
Visual input	67/80 (84%)	29/40 (73%)	*96/120 (80%)*
Total	*107/120 (89%)*	*99/120 (83%)*	

Table 11.11 DG: summary of temporal transcoding according to modality

In table 11.12 DG's transcoding performance is displayed in terms of the nature of temporal representation involved. The overall distribution of scores reflected a departure from that expected by chance, which suggested that there was a significant effect of time representation in DG's transcoding ($\chi^2 = 13.6$ (df,1) $p < .001$). Like all the subjects tested, his ability to manipulate a temporal code across modalities (eg. spoken to visual) was greater than his ability to translate time across codes ($\chi^2 = 4.7$ (df,1) $p < .05$). He was equally able to understand times in analogue or digital form but was notably poorer in reproducing analogue times than digital ($\chi^2 = 4.9$ (df,1) $p < .05$). When compared directly his analogue to analogue manipulations were clearly inferior to his manipulation of digital times ($\chi^2 = 9.261$ (df,1) $p < .05$), principally it seems, because he had more problems with production of analogue times than digital times. The fact that he scored

55/60 (91.7 %) on spoken production of analogue times but only 42/60 (70%) on visual analogue time production, suggests that this poor analogue time production is interpretable in terms of his difficulties in pre-categorical perceptual processing. There was no evidence to suggest that any of DG's time-transcoding difficulties could not be explained by impairments to more general cognitive processes.

	Analogue output	Digital output	*Total*
Analogue input	33/40 (83%)	69/80 (86%)	*102/120 (85%)*
Digital input	64/80 (80%)	40/40 (100%)	*104/120 (87%)*
Total	*97/120 (81%)*	*109/120 (91%)*	

Table 11.12 DG: summary of transcoding performance according to temporal code

11.3 Discussion

11.3 (i) Interpretation of the results

Time Comprehension

In section 11.1 it was proposed that 'clock-reading' ability was necessarily dependent upon certain cognitive operations which might be considered peripheral to the more abstract concept of time, but which were required to be able to tell the time satisfactorily. Any impairment in those cognitive skills would be expected primarily to affect the modality of stimulus presentation and response. In terms of modality of presentation in the present investigation, one subject showed significantly superior comprehension of auditorily over visually presented times. This was DG whose modality-specific comprehension problems can plausibly be attributed to a range of visual perceptual problems following a right parietal lesion. Surprisingly, AS did not

show the anticipated preference for visually presented material, perhaps because this also included written numerals with which he also had processing problems. Most importantly, DC showed a preference for visually presented material while VF showed a trend to the same effect. As these subjects had rather different neuropsychological profiles, the consistent outcome perhaps reflects familiarity with the visual modality in which telling the time usually takes place.

In terms of the nature of the temporal representation, VF and DC showed poorer understanding of analogue than digitally represented times whereas AS and DG showed no differences between temporal codes. This suggests that selective dysfunction of the requisite peripheral cognitive apparatus in the form of apperceptive or dysphasic/dyscalculic problems, is insufficient to impair the processing of one particular form of temporal notation in isolation. Evidence from AS suggests that digital times convey more complex information than mere numerals. He showed lexical errors in digital time production, consistent with more general lexical difficulties in arabic number production (with numbers > 3 digits). Yet he seemed to have less problems manipulating digital time representations than with other arabic number tasks. It may be tentatively suggested that just such an effect would be found after a superior left parietal lesion if digital times (as opposed to random number strings) had a crucial semantic (ie. left temporal) component which facilitated transcoding.

VF and DC had more generalised cognitive difficulties but still presented with rather different neuropsychological profiles, in the light of which it seems reasonable to speculate that the analogue and digital forms of time representation are constructs partially separable from their constituent numerical and perceptual aspects. Interpretation of time in analogue format may be especially difficult after brain injury, whilst digital representations may be relatively preserved..

Time Production

Considering modality of time reproduction, VF showed a trend towards superior spoken production of times whereas DC and AS showed a clear improvement when required to reproduce times visually. DG showed no effect of modality of production. In the case of AS his preference for visual reproduction is due to his expressive dysphasia. VF appears to show a different pattern than DC. For instance, DC's poorer spoken time than visual time production may also be attributable to impaired output systems, in his case an arabic number production deficit for 3-4 digit numbers. Yet the performances of these subjects are not entirely at odds with one another. Comparison of the data in tables 11.5 and 11.7 shows that both VF and DC perform similarly on spoken time production. but VF has particular problems in visual reproduction. Although she has no number production problems, it will be recalled that she was impaired on two line orientation tasks (see table 11.2) and this may well have contributed to this particular weakness with visual output. However, her visual analogue responses (53%) were no worse than her written digital responses (47%). Thus whilst time production can be adversely affected by expressive dysphasia, dyscalculia and apperceptive deficits, these dysfunctions may not be necessary for poor time production. VF showed inferior visual time production in the context of somewhat superior visual comprehension, suggesting that visual production of times (written digital or visual analogue) may involve other skills, probably time-specific, which were not assessed by the numerical and perceptual tests.

Obviously production of times is sensitive to the integrity of output pathways such that left hemisphere lesions may undermine spoken time production (case AS) and right-sided lesions compromise visual production (case DG). In fact AS showed no difference between his ability to reproduce analogue and digital times, his overwhelming handicap being in terms of modality of response. However, DG did show a somewhat greater aptitude for digital reproduction rather than analogue, which may again reflect his

relatively competent verbal skills. Conversely, VF showed a trend towards better production of analogue than digital notation and DC showed the same effect to a statistically significant extent. The fact that analogue time production was generally superior to digital time production (except, predictably, for DG) cannot simply reflect common experience with analogue clocks given the contrasting finding of superior comprehension of digital rather than analogue time. One means by which relatively good analogue time production could occur in the context of poorer analogue comprehension, is if there were functionally independent notation-specific comprehension and production systems in the manner proposed for numbers by McCloskey et al., (1991). Thus there would be separate processing routes to and from the subsystems of the model. In terms of time transcoding, damage to an input system would leave intact the analogue output system. However, more recent formulations of numerical processing systems have eschewed this approach as unnecessarily restrictive (Dehaene & Changeux,1993; Cipolotti,1995). More significantly, a 'lesion' of the analogue input system should still leave intact both digital representation systems, which would not produce the superiority of analogue over digital production demonstrated in the present study.

An alternative account may be sought in terms of a single transcoding processes operating on one form of temporal notation or another. A mechanism of this kind would not need separate input and output systems as the translation process could operate on either an abstract temporal representation or on whatever format the information was initially presented. However, such a model must incorporate separate *recognition* and *translation* phases. The recognition procedures at least, would need to be specific to a particular temporal notation (ie. analogue or digital). In effect, the system would need to first recognise the nature of the existing temporal code and then create a different representation via the translation process. A deficiency in the recognition phase affecting

specifically the analogue code would yield inferior analogue comprehension and could produce the relatively poorer performance on analogue-digital than digital-analogue transcoding that three of the four subjects showed.

The discussion so far has focused upon the modality and material specificity of processes required for clock reading. This is necessary to ascertain the extent to which the ability to tell the time is subsumed by more general cognitive processes. The results suggest that appreciation of time in its conventional notation shares some characteristics with numerical processing and does rely to an important degree upon the integrity of prerequisite numerical and perceptual capabilities. Any appreciation of how people tell the time would, though, be inadequate if reduced only to number processing. A thorough account of the time transcoding data clearly entails theoretical speculations well beyond the parameters of perceptual and numerical models. Just as Dehaene (1992) criticised the over-emphasis of number processing theories on syntactic processes at the expense of semantics, so there is a need to consider the relevance of the meaning associated with temporal notation, without which the present study would remain divorced from the broader scope of psychological time. The next section therefore develops the model presented at the outset of the chapter as it is argued, on the basis of empirical evidence, that telling the time not only involves general purpose numerical and perceptual skills but also invokes semantic representations of time (generally referred to as a concept of time). It will be proposed that representations of time which are embodied in conventional clock notation possess certain semantic attributes by virtue of their reference to temporal experience. The ability to tell the time therefore involves integration of both the ability to de-code the conventional clock notation and to relate this information to stored knowledge about what the notation represents. These two processes will be addressed in turn.

11.3 (ii) Towards an integrated model of telling the time

A clock-reading grammar

Acquiring familiarity with syntactic relations between elements in a number is widely recognised to be a rule-based learning process which is mastered with age (Power & Longuet-Higgins,1978) but which may break down after acquired brain damage (McCloskey & Aliminosa,1991). Following this line of reasoning, it may be useful to think of a similar rule-governed *grammar* being essential to telling the time. Accordingly, rules to time-telling may also be disrupted, possibly resulting in an "immature" response pattern similar to syntactic errors in a number processing system. Hence clock reading problems may arise without disruption to the abstract concept of time (see figure 1) because it is the appreciation of the grammar of clock reading (the de-coding rules) which is disturbed. In fact this is pretty much how Kartsounis and Crewes (1994) explained their patient: as an inability to retrieve facts about clocks and time, rather than an impaired concept of time.

The patients in the present study all showed adequate knowledge about the uses and appearance of clocks. For example DC, the most grossly cognitively impaired of the four cases reported, was able to correctly draw the numerals around a clock in 12- and 24-hour arrangements. He was also able to define a clock: " *to look at and read what the time is;*" to explain when they would be used, "*...to find out what the time is;*" and describe what kind of clocks one might experience "*...round clocks, I don't know what you'd call them; they're not digital ones.*" Given DC's general intellectual difficulties, this would appear adequate evidence of his residual knowledge about the uses and appearances of clocks. In contrast to this relatively preserved information, he shows difficulties which may be attributed to problems utilising a clock-reading grammar, suggesting a dissociation between different forms of knowledge about clocks. In the light of evidence that autobiographical experience contributes to the preservation of

semantic memory (Snowden et al.,1994) it seems reasonable to presume that the preservation of knowledge about the functions of clocks is related to experience. However, experience with clocks appears to be insufficient to spare the ability to tell the time, presumably because this skill also requires familiarity with clock grammatical convention, which may be impaired in the absence of loss of knowledge about clock functions.

The semantic representation of clock-time

It has been stated at various points throughout the thesis that time perception is an adaptive capability. In its most sophisticated evolution this entails a standard means of communicating about time - the clock. It may conceivably be possible to tell the time without attaching any meaning to it, just as one can with calculations (Delazar & Benke,1997), but it is unlikely that this would occur in such a conceptual vacuum. It seems much more likely that the process of clock reading is endowed with meaning, and that such meaning is derived through experience, with the results that numerical and analogue representations of time come to be associated with everyday actions. Although these relations are semantically-based they need not depend solely upon consensus about specific temporal facts such as the number of minutes in an hour, or the proper time to eat breakfast. Instead one might expect individual variation in meaning and significance associated with such representations. In a similar vein Cohen et al., (1994) proposed that frequently encountered numbers promote access to a specific idiosyncratic store of number knowledge, such as one's age. It seems reasonable that a similar dynamic set of associations (such as how long an activity has endured, how soon lunchtime is, or when some future act needs to be performed) may be incorporated into telling the time in real life contexts. For example, a child finishing school at 3:35pm. is likely to endow this time with more significance than would a 9-to-5pm office worker.

If this argument is accepted, it follows that clock reading might be facilitated by cues to events in time. Preliminary reports suggest that this might indeed be demonstrable. When provided with ten common daily activities and asked to indicate when they would usually perform these all four subjects in the present study were able to indicate appropriate times for a range of activities. This suggests a reasonable understanding of the relation between temporal orientation and relevant activity and hints at the possibility that retrieval of representations of time can be facilitated by strengthening associations with specific events.

In order to develop the model at the start of the chapter it is necessary to give a name to these links between telling the time and temporally mediated action. For convenience they may be called *time-action relations*, a term which reflects the clock-governed nature of much of our behaviour. It is proposed that time-action relations are necessary to give meaning to the otherwise abstract process of telling the time. Hence the implications of difficulties in telling the time cannot be appreciated outside a functional framework, but this requires that the relation between procedures for clock reading and associations with temporal concepts need to be clarified. Some of these distinctions can now be articulated from evidence that has accumulated from the chapters reported thus far. On this basis it is proposed that the psychological experience of time incorporates the concepts of both clocks and time, each of which has a number of separate aspects underlain by different cognitive processes, as follows:

1. Knowledge about time can be considered in terms of either semantic memory, episodic memory or executive skills. The contribution of semantic memory contribution is in the form of a store of temporal facts, such as the number of days in a week, and other dating systems (see chapter 8). Temporal knowledge is also informed by the experience of duration which is mediated by episodic memory and attentional influences (chapters 9

and 10). Finally, factual information and personal experience provide the raw material for the operation of executive processes in temporal reasoning (see next section).

2. In addition to knowledge about time itself, an essential aspect of temporal experience is knowledge about clocks. This has two components: the perceptual and conceptual information about the appearance and uses of clocks on the one hand, and in addition the conventional grammar of clock reading. It is information derived from the latter which provides a link with knowledge about time (temporal semantics and experienced duration) because the development of a consistent concept of duration involves experience of events in relation to a standard reference such as clock time (Friedman, 1982a; Huttenlocher et al.,1988).

Just as the Piagetian notion of a number concept was abandoned for one of fractionating numerical skills (Dehaene,1992), it is now possible to modify the provisional model in figure 11.1 by substituting the concept of time with multiple representations of different aspects of temporal experience. As proposed above, semantic representation of time have both a context-independent aspect and an experientially-mediated component based on time-action relations. The ability to tell the time seems to require identification of a particular temporal code or format for representing time, for which knowledge about clocks and clock-reading convention is relevant. An additional translation process enables time in a recognised code to be translated into an equivalent temporal format. This permits the pattern of relatively good analogue time reproduction in the context of poorer analogue than digital time comprehension shown by the two subjects without lateralised brain damage. This hypothesis is illustrated in figure 11.2 below, showing the normal time-reading process by which grammatically-coded input activates associations in memory.

INPUT

KNOWLEDGE ABOUT CLOCKS

TEMPORAL CODE
RECOGNITION PHASE

Clock - reading grammar

Clock structure and
function

Pattern Analysis

Facts about time

Time - action relations

REPRESENTATIONS OF TIME

Analogue
code

Digital
code

Analogue
code

Digital
code

TRANSLATION PHASE
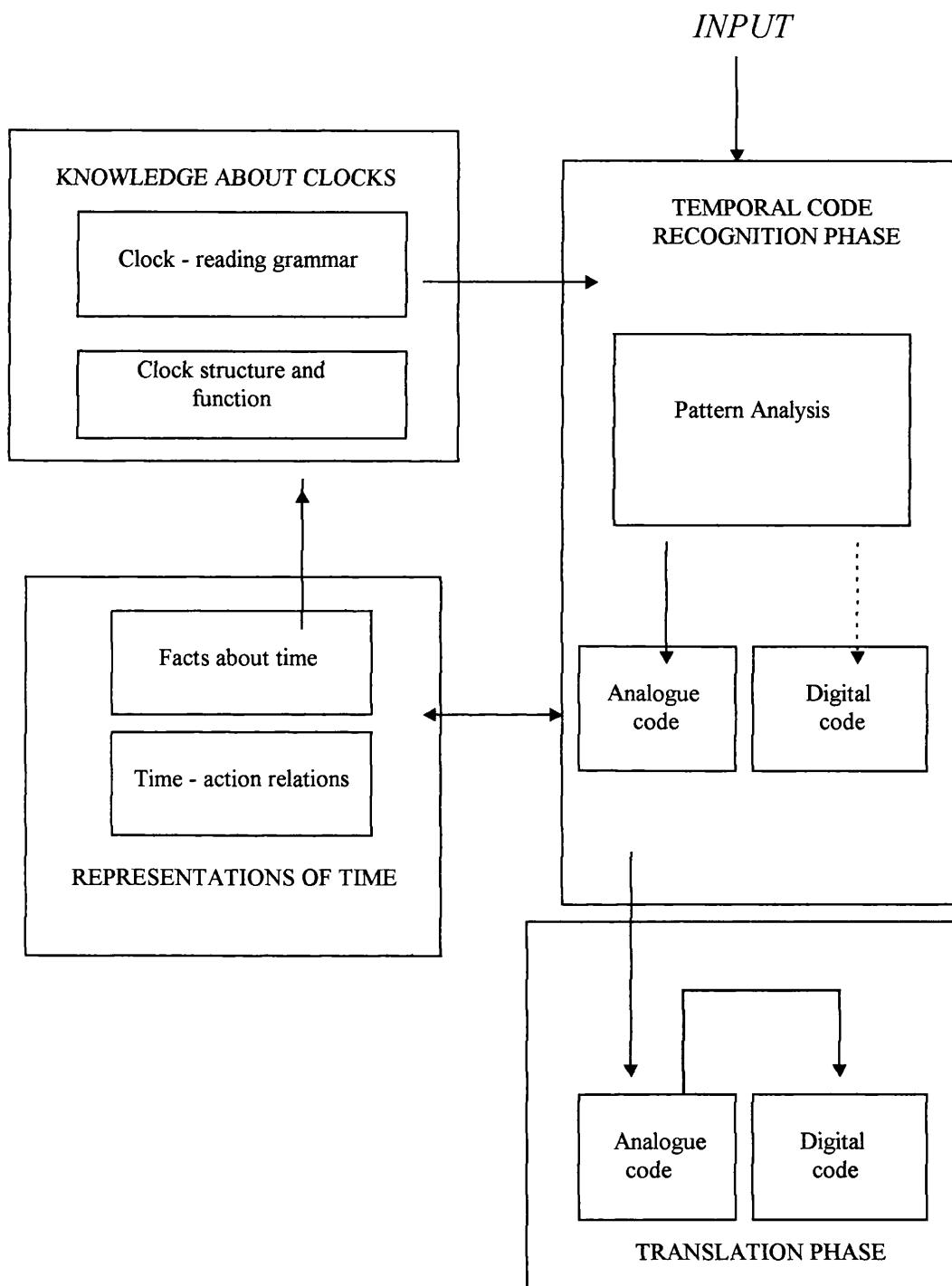
Figure 11.2 Modified model of processes involved in telling the time.

Summary

The results of the present study go some way towards clarifying the relationship between numerical and visual skills and the ability to tell the time, such that integrity of modality-specific processes is necessary but not sufficient for accurate time reading in cases of generalised cognitive impairment. The evidence also suggests a distinction between knowledge about functions and appearances of clocks, and the grammar of clock reading, of which the latter may be more related to experienced duration. A general semantic representation of time may be replaced with related frameworks for representing different aspects of temporal experience (clocks, dates, actions) in which telling the time represents an intermediate process between pre-requisite cognitive competencies and semantic integration.

SECTION FOUR

Executive skills and Psychological Time

Chapter 12

Executive skills and Psychological Time:
Time estimation as cognitive estimation

12.1 Introduction

A premise has been cited throughout the thesis that the regulation of behaviour within a variety of time constraints can be conceptualised as problem solving behaviour. Temporal problem solving or reasoning is essential to effective individual and social functioning but any deficiencies in these skills are less likely to be demonstrated within the strictures of conventional neuropsychological assessment than in functional situations (see chapter 13 to follow). However, as suggested in chapter 10, poor temporal reasoning may constitute one of several factors which can undermine verbal time estimation methods. Indeed, as reported in chapter 10, there is some evidence already that time estimation is related to the ability to perform cognitive estimates (Shaw & Aggleton,1994). It is therefore important to develop a means of assessing temporal estimation in clinical populations. This present chapter is specifically concerned with the development of such a measure along the lines of the original Cognitive Estimates Test (CET).

Shallice and Evans (1978) developed the Cognitive Estimates Test in an attempt to quantify the tendency of some frontal patients to produce bizarre estimates in response to questions for which no specific answer was readily available. They devised questions, requiring no specialist knowledge, for which an appropriate strategy would have to be developed: "answering such questions satisfactorily stresses the abilities of selecting an appropriate cognitive plan and of checking any putative answer obtained as much as the ability of carrying out the selected plan," (Shallice & Evans,1978; pg.295). The authors showed that patients with unilateral frontal lesions produced significantly more extreme

showed that patients with unilateral frontal lesions produced significantly more extreme responses than did posterior-lesioned subjects or extra-cerebral lesioned patients. Analyses of covariance showed that these difficulties were not attributable to general intellectual ability (Raven's Matrices) or calculation skills (WAIS Arithmetic subtest). However, their extra-cerebral control group at the time was small (N=25) and little information was provided that demonstrated how adequately patient groups were matched on general intellectual measures.

Leng and Parkin (1988) reported that seven alcoholic Korsakoff's patients who performed satisfactorily on the CET compared to the Wisconsin Card Sorting Test (WCST), whereas five post-encephalitic patients showed the converse pattern of poorer performance on the CET. The authors suggest that the encephalitis patients' adequate performance on the WCST reflects an absence of dorso-lateral damage but that poor scores on the CET reflects likely orbito-frontal damage (though no evidence is presented to show they had more than the characteristic bilateral temporal lobe pathology). The CET might also be sensitive to semantic access difficulties, as suggested by Kopelman (1991) who found that this test did not correlate with other supposed 'frontal' tasks. However, Leng and Parkin's (1988) CET control group was very small (N=7) which limits the validity of the reported group differences on the CET.

Subsequently, Shoqeirat et al. (1990) tested 16 Wernicke-Korsakoff cases, 10 post-encephalitic patients and five anterior communicating artery aneurysm cases, all of whom showed below normal scores on the CET, compared to a larger group of 31 controls. The authors noted the variability of amnesic patients to perform frontal-lobe tasks which behoves cautious interpretation of small group results. By contrast, Shallice and Burgess (1991) failed to reveal any deficits on conventional frontal tests, including the CET, with three traumatic orbito-frontal brain-injured patients. Similarly, Goldstein

et al. (1993) reported a patient who underwent a unilateral frontal lobectomy who performed better than most controls on the CET (despite showing rather concrete proverb interpretations, suggestive of frontal dysfunction).

The need for more adequate normative data on the CET is generally recognised in view of the limited numbers of controls in the original and subsequent studies. Recently, O'Carroll, Egan and MacKenzie (1994) collected normative data from 150 healthy controls (mean age 51.5 years) which demonstrated generally[error] higher scores for females than males (mean = 6.2 vs. 4.5), as well as rather higher normative scores overall (mean = 5.3 [SD 3.6]). This is consistent with Tyerman's (1987) control data (table 12.3 below) but they were derived from younger orthopaedic patients (mean age 21.6 years). Somewhat lower error scores have also been reported amongst some control groups (Leng & Parkin,1988; Shoqeirat et al.,1990; Diamond et al.,1996) but typically the nature of the controls has been underspecified.

In terms of its psychometric composition the CET is rather unsatisfactory, the ten items being associated with five different factors on principal component analysis (O'Carroll et al.,1994). This is consistent with earlier reports which suggested that the CET correlated poorly with other frontal tasks and that impaired performance could result from multiple deficits (Shoqeirat et al.,1990; Kopelman,1991). In fact, the multi-faceted nature of the CET not only makes difficult comparisons with other more specific frontal tasks, but also complicates its interpretation. Many of the research problems using the CET might be eased using a conceptually-related test which avoided the multiplicity of domains of questioning in the CET (eg. height, speed, age, length, weight, population density). Therefore a *Temporal Cognitive Estimates task (TET)* was developed to measure tendency towards extreme estimations of duration across a range of activities. If the strategy-based composition of the CET is valid and clinically useful then difficulties

might also be apparent on a more restricted set of questions. Furthermore, scoring consistency should be easier to maintain on a continuous dimension such as time, thus avoiding the individual differences apparent in scoring the CET (O'Carroll et al.,1994).

12.2 Developing a Temporal Cognitive Estimates test

The original Shallice and Evans (1978) questions contained a number of *knowledge items* reportedly dependent on semantic knowledge for accurate response, and *estimation items* requiring formulation of an appropriate plan. The final ten most discriminating estimation items also included one knowledge item which was also shown to be sensitive to bizarreness of response characteristic of patients with anterior lesions. A similar format was followed with the Temporal Estimates task (TET).

The test comprised thirty questions about activity durations ranging from activities which could be considered heavily dependent on semantic knowledge (eg. what is the fastest time some one could run one hundred metres/yards?) to those for which little obvious plan was apparent (eg. how long would it take for a cup of coffee to go cold?). Thus there was a kind of continuum from associative to strategic recall. All the questions referred to familiar activities to ensure that poor performance was due to strategy formulation and estimation difficulties rather than unfamiliarity with the question matter (as may occur in the original CET). The questions are shown below in the form that they were administered to subjects (table 12.1).

Two hypotheses were tested in this study. The complex underlying nature of the CET may reduce its sensitivity to specific deficits of estimation. It was therefore predicted that the simpler format of a single factor temporal estimation task would be more sensitive to extremes of estimation attributable to frontal lobe dysfunction. The common concern of the uniqueness or otherwise of temporal information is also relevant. Both

the CET and the TET are hypothesised to utilise the same processes in plan formulation and problem solving, and therefore performance on both tasks should be strongly related. Thus temporal information is employed in the TET to solve practical problems inherent in the original CET, rather than to justify special status for temporal information processing in this instance. Nevertheless, if successful the results will vindicate further use of temporal measures as uni-dimensional indices of cognitive estimation.

A secondary issue regarding the continuity of time scales was also to be addressed. Previous chapters have suggested that verbal time estimates might be confounded by response bias or reasoning difficulties, but inevitably the experimental intervals employed lasted a few minutes only, whereas functionally it is more important to know how people experience time and regulate their behaviour over much longer periods. Failure to show that reasoning problems were selective for specific temporal periods (eg. minutes, days weeks etc.) would nevertheless constitute useful support for continuing to make generalisations about function on the basis of the restricted range of intervals used in most cognitive studies.

How long would it take a person to...
1. Walk a mile?
2. Boil a kettle?
3. Recite the months of the year backwards?
4. Iron a shirt?
5. Tie your shoe laces?
6. Run a marathon?
7. Dial a telephone number?
8. Read a page in a novel?
9. Count backwards from 30?
10. Bake a potato?
11. Sing the National Anthem?

Table 12.1 Continued

12. Train to be a vet?

13. Fly to America on Concorde?

14. Eat a bowl of soup?

15. Fall asleep in bed at night?

16. Train as a brain surgeon?

17. Travel to France on the ferry?

How long would it take...

18. A cup of coffee to go cold?

19. To develop a photograph?

Table 12.1 continued

How long would it take...

20. For a second class letter to reach its destination?

21. For iron to show rust if left outdoors?

How long is...

22. The average waiting time for a bus?

23. The approximate time between one full moon and the next?

24. The duration of a football match?

25. The gestation period for an elephant?

26. The duration of an average automatic washing machine programme?

27. An average film at the cinema?

28. How long is it from Easter to Whitsun?

What is...

29. The fastest time someone has run 100 metres/yards?

30. The journey time by train from London to Edinburgh?

Table 12.1 The original temporal estimation questions used in the pilot study

12.3 Method

Materials

A pilot Temporal Estimates Test (TET) was devised comprising 30 questions requiring duration estimations for time intervals ranging from a few seconds to several years. This

was used as the basis for developing a shorter version constituting the most discriminating items (see appendix C).

Subjects

In the preliminary study 17 patients with severe closed head injuries (PTA > 48 hours/GCS < 8) participated. Some completed the tests as acute hospital inpatients but most were administered the tasks as rehabilitation outpatients. Their performance was compared with a slightly older ($t = 2.64, p < .05$) control group of 43 orthopaedic patients which was also recruited from the acute hospital wards and from an outpatient clinic. For the second validation study a larger group of 37 severely head-injured subjects, matched with the controls for age was recruited. Table 12.2 summarises the characteristics of the three subjects groups. There was no difference across the groups in NART-estimated intellectual level, but the principal head injury group tended to comprise individuals with more prolonged and in this sense more severe cognitive problems.

	Orthopaedic controls	Head injury (pilot group)	Head Injury (main study)
N	43	17	37
Age (yrs.months)	42.3 (15.2)	31.6 (10.4)	37.9 (12.7)
NART-IQ	103.0 (11.0)	97.1 (8.1)	99.1 (10.7)

Table 12.2. Characteristics of subjects in temporal estimates study

Procedure

In the preliminary study subjects were administered both the original CET and the 30-item Temporal Estimates Test (TET). Wherever possible the pro-rated IQ scores for the head-injured patients were also estimated on a shortened WAIS-R, and both groups were administered the re-standardised NART (Nelson & Willison, 1991). In the second phase, the responses of the pilot group were compared with the range of responses from the orthopaedic sample to yield the 12 most discriminating items (appendix 12.1). These were used in a short-form TET which was then adminstered, along with the original CET, to a larger sample of 37 age-matched severely head-injured subjects in the main study. A system of deviation scores (0 to 3) was used based on the standard deviation of the normative sample. Following Smith and Milner (1984) an error was defined as a response two standard deviations outside the control mean, ie. a response two SDs above or below the control mean would score 1, an answer three SD.s outside the control mean scores 2. A similar approach has been used in an American version of the original CET (Axelrod & Millis,1994).

12.4 Results

12. 4 (i) Cognitive estimates test

The CET scores of the head injured groups were compared to the orthopaedic controls and those reported from other normative samples (table 12.3). There was no correlation between NART IQ and CET score for the controls or head injured subjects. There were however significant between-group differences in CET score (F=11.3, p <.001) with F-tests revealing that although the controls had performed similarly to the pilot head injury sample who were significantly younger, most importantly controls had obtained fewer error scores than the larger age-matched head injury sample (F=2.55, p <.01) who scored poorly themselves compared to the pilot head injury group (F=2.81, p <.05). The mean control score of 4.33 falls between those reported for healthy subjects (O'Carroll et al.,1994) and young orthopaedics (Tyerman,1987) and the original Shallice and Evans (1978) sample. The mean score of 9.03 from the larger head injured group is

understandably well above the mean of 5.7 (SD. 4.4) recently reported for a mixed moderate-severe head injury group (Taylor & O'Carroll,1995) but is more consistent with the results of Shallice and Evans' (1978) slightly older frontal lesion groups.

	Mean	s.d.	N	Sample
Present study				
Head injury pilot	7.75	3.26	17	Severely head injured
Main head injury group	9.03	5.63	37	Severely head injured
Controls	4.33	3.53	43	Orthopaedic controls
Other normative samples				
Shallice & Evans (1978)			25	extra-cerebral lesions
Tyerman (1987)	5.73	2.85	36	young orthopaedics
Leng & Parkin (1988)	2.9	3.8	7	
Shoqueirat et al. (1990)	3.7	3.0		
Shallice & Burgess (1991)	3.0	2.6	24	
O'Carroll et al. (1994)	5.3	3.6	150	healthy controls
Diamond et al. (1996)	3.7	3.0	6	

Table 12.3 Scores obtained on the Cognitive Estimates Test by severely head injured subjects in relation to normative scores.

12.4 (ii) Temporal estimates test

The deviation scoring system was used to rate control responses, those of the second head injury sample, and to compare the answers given by the original pilot sample (who had performed similarly to the controls on the CET). Using ANOVA it was shown that scores varied significantly across the groups (F=28.9, p<.001) with both head injured samples performing similarly to one another (despite some differences in severity) and

both showing significantly higher error scores than the controls ($p<.001$). The range of temporal estimates scores is detailed in table 12.4 and illustrated graphically in figure 12.1 below.

Subject group	**Controls**	**Pilot head injury**	**Head injury**
Mean (SD.)	4.02 (2.6)	8.94 (6.8)	12.84 (6.4)
Median	4.00	8.00	10.00
95% C.I.	3.21 - 4.84	5.46 - 12.46	10.72 - 14.96

Table 12.4 Deviation scores obtained on the 12-item Temporal Estimates Test.

For the control group there was no relation between TET scores and either NART IQ or CET performance. By contrast, for head injured subjects TET scores were predictable from NART-estimated IQ ($F=5.32$, $p < .01$) and highly correlated with CET ($r = 0.73$, $p < .001$). The TET results of the original control group, the pilot head injury sample and the larger group were compared with their performance on the CET (figure 12.2).

Temporal Estimates Test
modified version
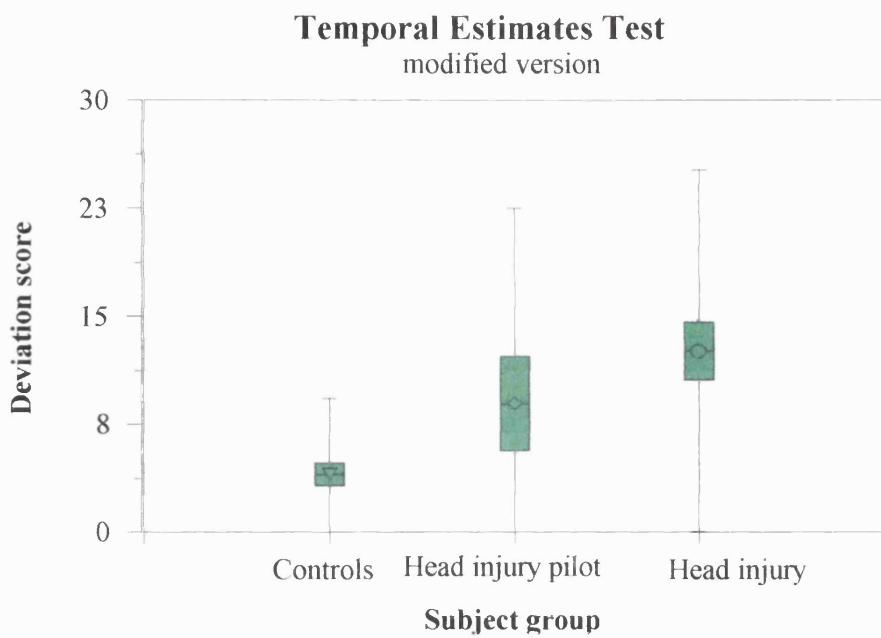
Figure 12.1 Response variability by subjects on the Temporal Estimates Test.
(Plot shows means, standard errors and standard deviations)

It can be seen clearly that the TET is particularly sensitive to brain injury without demonstrating any bias towards higher scores in controls.

Comparison of CET and TET scores
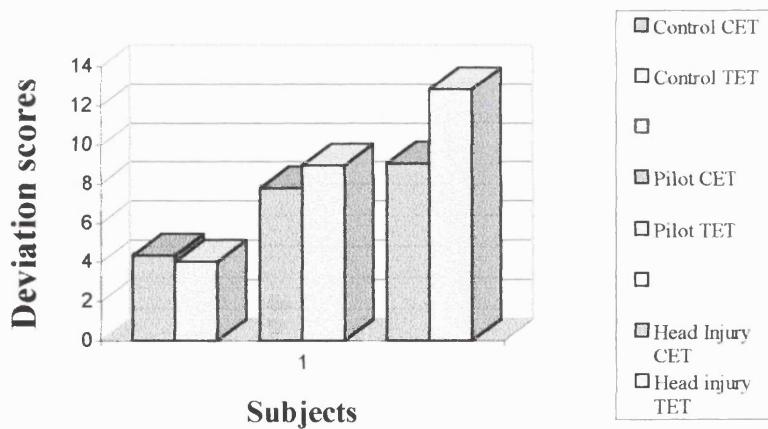
Figure 12.2 Deviation scores for all subjects on Cognitive
Estimates and Temporal Estimates Tasks.

12.5 Discussion

The results support the original observations of Shallice and Evans (1978) that cerebral-lesioned patients may have difficulties solving novel problems for which no readily apparent strategy existed. Unfortunately, it proved unfeasible to assess current intellectual level in the head injured group and thus it is not possible to establish the sensitivity of the TET to general intellectual status. There was no relation for the controls, but given the strong link between NART-estimated IQ and TET scores for the head injury group, then current cognitive abilities may well be expected to have some influence on the results. Fortunately the TET was not developed as a localising "frontal" test and, given the continued doubts about the selectivity of the original CET (Taylor & O'Carroll,1995), it is more appropriately considered an index of reasoning problems which may have important functional implications. Indeed, there are a number of difficulties associated with the use of the original CET, largely because of the heterogeneity of the items used and the difficulties associated with scoring it reliably. From the results obtained in the present study the TET appears to offer a much simpler, means of assessing cognitive estimation.

However, the TET is not simply a more simple measure of cognitive estimation. Certainly, head injured subjects produced more variable and less accurate responses to estimation questions than did controls, on both the CET and the TET, which is consistent with the tendency of individuals with frontal lobe damage to adopt bizarre hypotheses (Burgess & Shallice,1996). Thus temporal reasoning can be disrupted much the same as any of the other dimensions employed in the CET. Nevertheless the results also strongly suggest that temporal estimation may be a more sensitive index of estimation difficulties. This is particularly interesting in view of the great variability of responses to time estimation produced by head injured subjects in previous chapters, and the wide range of normal variability often elicited by cognitive estimate-type tasks (Dowker et al.,1996).

These observations are significant are two accounts. Firstly, because they support the possibility, discussed in previous chapters, that biases in reasoning about duration might confound the verbal time estimates typically required by studies of temporal experience. However, as well as providing salutary grounds for caution in the interpretation of clinical experimental studies of time experience, there is another sense in which these results are relevant to the concept of psychological time. Adaptive behaviour is amongst many other things, timely behaviour. This requires the ability to monitor on-going action and modify plans accordingly on the basis of any emerging mismatch between expectancies and anticipated outcomes. To the extent that these operations involve estimation of temporal contingencies (and it is highly likely that they do) then deficits in temporal reasoning are likely to contribute to inefficient self-regulation of action. Hence these results support the notion that the oft-neglected temporal aspects of cognition (discussed in chapter 2) may be particularly pertinent indices of dysfunction. The manifestation of these problems in functional contexts is illustrated in the penultimate chapter 13.

Chapter 13

Executive skills and Psychological Time:
Temporal problem solving in functional context

13.1 Introduction

In chapter 12 evidence was accrued that time estimation after brain injury may be confounded by reasoning problems, thus confirming the suggestions raised in earlier chapters. This findings supports the view that appreciation of temporal deficits associated with brain damage requires a broad sweep of analysis (see chapter 3). It has also been argued in chapter 3 and elsewhere in the thesis that time awareness is essentially a functional capability and deficits leading to inability to regulate action in time can lead to considerable problems (see also chapter 10). The present chapter is the final empirical section, reflecting the development through the thesis of the concept of psychological time and its cognitive components, by illustrating the functional disability arising from impaired temporal organisation of behaviour.

Within the neuropsychological literature pertaining to temporal disorganisation of action (Eslinger & Damasio,1985; Grafman et al.,1993; Brazzelli et al.,1994; Dimitrov et al.,1996) perhaps the most comprehensive attempt to encapsulate the functional dimension has been by Shallice and Burgess (1991). They developed the Multiple Errands task to assess the kinds of supervisory control over behaviour to which standard psychological testing was generally insensitive. It is now well recognised that patients can display a range of deficits under the rubric of "strategy application" following frontal lesions, both bilateral (Shallice & Burgess,1991) and unilateral (Goldstein et al.,1993), in the context of well above average general intellectual functioning. To appreciate the importance of temporal processing in this disorder, consider the examples given by Shallice and Burgess: plan formulation and modification, prospective memory markers to interrupt on-going behaviour at a given time, and articulation and evaluation of goals.

The essence of these difficulties is the inability to act out intentions at the relevant time. More recently, Burgess and Shallice (1997) have argued that the primary deficit in SAD is one of a failure of prospective remembering, in the context of more or less intact retrospective memory processes. To date none of the reported cases of strategy application disorder (SAD) has emphasised its underlying temporal aspect or explored the role of memory processes. Nonetheless, the prospective realisation of intentions requires many aspects of temporal processing, including an appreciation of time constraints, anticipation of the likely durations of tasks, and the ability to monitor temporal passage concurrently with task execution. These issues will be the focus of the single case presented below.

13.2 A case of Strategy Application Disorder and memory impairment.

JW was a 59 year-old (date of birth 17.2.34) right-handed woman initially referred for a neurological opinion following a two year period of worsening memory functioning and suggestions of complex partial seizures. JW herself was unaware of these episodes and denied any memory problems. There were no abnormal neurological signs other than bilateral anosmia from a car accident five years previously (no other details were on record).

JW underwent neuropsychological testing which yielded intellectual and memory scores within the low average range, surprisingly normal given her family's report of her severe forgetfulness and disorganisation. There was also a suggestion of a degree of frontal dysfunction but given her low average intellectual level the interpretation was somewhat equivocal. Subsequently an MRI scan revealed a very large olfactory groove meningioma with surrounding oedema in both frontal lobes. Because of the inevitable need to excision the tumour, further neuropsychological tests were undertaken with JW prior to her surgery and readministered post-operatively. The general intellectual tests are summarised in table 13.1 below.

Task		Pre-operative		Post-operative
National Adult Reading Test (predicted FSIQ)		95		
WAIS-R	Verbal IQ (pro-rated)	86		86
	Performance IQ (pro-rated)	88		80
Cognitive Estimates		12	*within normal limits*	14
Trail-Making	A:	56"	*within*	33"
	B:	124"	*normal limits*	203"
Modified Card Sorting Task		2 categories *impaired*		6 categories *satisfactory*
FAS Word fluency		19	*(35 expected)*	21
Proverb Interpretation		2/10	*poor*	5/10
Hayling Sentence Completion				
Response time total		280"		120"
Response suppression				
Errors		13	*< 2 SD above control mean*	12
Six Elements task				
No. tasks completed		5	*within*	5
No. rule breaks		0	*normal limits*	0

Table 13.1 JW: Results of neuropsychological assessment three months before and six months after surgical excision of tumour.

In addition, and in response to JW's performance on standard memory tests (surprisingly adequate given her reported memory loss), two further memory tasks were undertaken, both of which tend to be sensitive to strategic aspects of memory functioning. Thus the Rivermead Behavioural Memory Test (Wilson et al.,1985) and the Autobiographical Memory Interview (Kopelman et al.,1989) were also adminstered. The results of memory testing are shown in table 13.2. It is clear from these results that JW has severe deficits of autobiographical recall (personal incidents) and "behavioural memory" the severity of which is not indicated by the more conventional recognition memory and recall tests. There is little significant change in this pattern of memory performance over time although her post-operative verbal recall was slightly poorer (see Incisa della Rocchetta & Milner (1993) regarding the left frontal lobe in strategic verbal retrieval).

This discrepancy between observed or reported difficulties in daily functioning and test results is commonly encountered with executive dysfunctions but suggests that a similar profile of impairment may be apparent in other domains such as memory which are not generally considered "frontal" skills but which may involve anterior brain regions by virtue of dependence on strategic processes, particularly contextual retrieval (Einstein & McDaniel,1996).

	28.10.93	19.7.94
Recognition Memory Test		
Words	41 (average)	39 (low average)
Faces	38 (low average)	37 (borderline)
AMIPB Story recall		
Immediate	21/56 (15-25%)	6/60 (< 10%)
Delayed	19/56 (15-25%)	4/60 (<10%)
Information retained	90% (50-75%)	66% (<10%)
AMIPB Figure Recall		
Immediate	40/80 (10-15%)	40/80 (10-25%)
Delayed	33/80 (15 %)	39/80 (10-25%)
Information retained	83% (15-25%)	98% (50%)

Autobiographical Memory Interview*	Personal Semantics	Incidents	Personal Semantics	Incidents
Childhood	13 (11)	0 (3)	15 (11)	0 (3)
Early Adult Life	18 (14)	0 (3)	17 (14)	0 (3)
Recent Life	21 (17)	3 (5)	20 (17)	1 (5)

Rivermead Behavioural Memory Test	28.10.93	19.7.94
Screening score	4 (<5%)	7 (<5%)
Std. Profile Score	6 (<1%)	16 (<1%)

Table 13.2 JW's performance on memory tasks before and after surgery.

* Cut-off scores shown in parentheses.

To investigate the functional consequences of JW's difficulties, the Multiple Errands task, was also administered as described in detail by Shallice & Burgess (1991). This involves the subject carrying out a number of instructions in what is mainly a shopping task in an unfamiliar environment, according to specific constraints or rules. These include: entering a shop only in order to purchase an item, visiting each shop no more than once, and arranging to meet the examiner at a specified location fifteen minutes from task onset. Competent performance on the Multiple Errands task requires appreciation of actions implied in the instructions as well as social judgement, planning and problem solving. Although it was originally used with patients of superior intellectual ability, Aitken and her colleagues have validated its use with patients functioning at rather lower levels (Aitken et al,1993).

Aitken et al. (1993) standardised a scoring system attributing penalty points to failed subtasks that were either omitted (2 penalty points) or partially executed (1 point). Other aspects of a subject's performance are described as either inefficiencies (failure to use the most effective strategy), interpretation failures, or rule breaks. In JW's case this test was undertaken in a well-defined undercover shopping precinct. Throughout the test she was shadowed by the psychologist to whom she was required to report after each item was purchased. The results of this task are detailed in table 13.3 below.

Overall, JW showed considerable difficulties, her most frequent error was failure to complete a task. She omitted (*Omitted*) to buy several items from her shopping list because she could not find a suitable retail outlet or forgot to check her existing purchases. A relatively high proportion of task failures is consistent with the results reported by Aitken for both controls and patient groups (Aitken et al.,1993) but the number of JW's errors is well within the brain injury group range and outside the control group range.

Error type	Pre-operatively		Post-operatively	
	frequency	*error scores*	*frequency*	*error scores*
Inefficiencies	4	4	3	3
Interpretation failures	0	0	0	0
Rule breaks	2	4	1	2
Task failures	12	21	11	18
Total errors	**18**	**29**	**15**	**23**
Shallice & Burgess (1991) controls (means and SDs)	1.1 (1.4)	4.6 (2.1)		
Aitken et al, (1993) controls (medians and ranges)	3.0 (0-10)	6.0 (1-16)		

Table 13.3. JW's pre- and post-operative performance on the Multiple Errands Task.

compared with published data from normal controls

Inevitably, not all of her failings could not be described as temporal processing deficits. For example, she bought white bread instead of the prescribed brown loaf, saying later that she preferred to eat white bread, despite having been told to follow the instructions exactly); she purchased half a pound instead of one pound of apples (later declaring that half a pound was plenty). Nevertheless many of her errors were time-based, thus she arrived at an agreed meeting place eleven minutes late (she said she preferred to get the shopping out of the way first). She also showed a number of inefficiencies due to poor

sequencing of the tasks. For instance, she decided to address a postcard ready to send before finding a stamp vendors or acquiring all the information to be written on the reverse prior to posting. She then decided to buy some food items from her list, forgetting that she had not filled the postcard with the requisite information. Thus, when she came to post the card it was incomplete. Post-operatively, she continued to show poor temporal organisation to her behaviour. Thus she entered a newsagents three times to purchase three items from her shopping list (a packet of mints, a soft drink and a magazine). She spent much of the time wandering between shops, making occasional references to her shopping list but without an apparent objective in mind or evident planning of her route around the precinct. Though she showed a number of inefficiencies and one rule break, the majority of JW's errors were task failures, a pattern of impairment qualitatively similar to her pre-operative performance.

13.3 Discussion

JW's symptoms of memory loss and disorientation were caused by underlying frontal lobe pathology confirmed by MRI scan. Bifrontal craniotomy revealed a large meningioma situated midline surrounding the anterior fossa. This was noted to be severely compromising the left frontal lobe and was reached via a limited right frontal lobectomy. A second MRI scan two months after surgery confirmed extensive damage to the medial and inferior left frontal lobe in addition to the right frontal surgical lesion. Thus cerebral damage was confined entirely to the prefrontal regions with the integrity of the hippocampal-fornix-mamillary body pathways well preserved.

13.3 (i) The cognitive basis of temporal problem solving

On testing JW demonstrated preserved language skills (naming, auditory comprehension and reading), average verbal short term memory and satisfactory visual perceptual skills. However, she also showed marked impairment of autobiographical event recall and

behavioural memory in contrast to her recall and recognition memory scores which were broadly compatible with her low average level of intellectual functioning. She showed difficulties on some frontal-sensitive tasks (word fluency, card sorting, anomalous sentence completion) but it was her disordered performance on the Multiple Errands task which illustrated her poor strategy application skills most vividly. JW's scores on executive tasks and memory tests after surgery were very similar to her pre-operative performance, presumably due to persisting frontal damage caused by the meningioma and the surgical lesion. Therefore the JW's neuropsychological impairment pre- and post-surgery will be treated as the same disorder in spite of the change in her medical condition.

There are a number of indications from the Multiple Errands test suggesting that many of JW's dysexecutive and memory problems could be characterised by poor temporal organisation. For example, one clear sign of temporal dysfunction was in JW's difficulties with prospective memory, evident on the RBMT and the Multiple Errands task. Prospective memory is a goal-directed process (Meacham, 1982), requiring activation of an internally-generated responses at some future time (Harris,1984). This time-based process is an integral component of the strategy application disorder.

Awareness of temporal context in functional situations can be thought of therefore as an essential to the regulation of behaviour within temporal constraints. This demands, not only that current action is monitored in terms of temporal passage, but that relevant information in memory is retrieved, with the aid of temporal context, at the right moment. Contextual retrieval strategies are mostly self-initiated and goal-directed (Craik,1983; see chapters 4 and 7) and appear to be time-based processes for which the frontal lobes are also known to be crucial (Glisky,1996). The ability to act upon intention is triggered by the activation of relevant retrieval context, the most effective

kind being one where many aspects of a future scenario have been considered. Interestingly, there are similarities between the use of contextual retrieval in autobiographical memory and for the process of imagining future scenarios required for prospective remembering (Williams et al.,1996). It is known that impaired autobiographical memory is associated with deficits in organisational, contextual and strategic aspects of recall (chapter 4) and attributed to anterior brain dysfunction (Moscovitch,1989). Hence Burgess and Shallice (1997) suggested that complex retrieval contexts for prospective remembering are formed by using many of the same cognitive mechanisms involved in autobiographical recollection. On this basis it is proposed that executive control processes mediate both the creation of intention and the development of appropriate retrieval contexts and subsequent activation of these 'temporal markers'. This pattern of memory deficit and strategy application disorder displayed by JW illustrates the central importance of the temporal organisation of cognition. The fact that these memory deficits and to a lesser extent executive problems were not so evident on more formal standard testing lends credence to the view that time experience is essentially a functional phenomenon with grave consequences for everyday living even in the context of mild deficits on testing.

13.3 (ii) The neurological basis of temporal problem solving

The role of the frontal lobes in temporal information processing remains somewhat controversial. For example, concerning whether frontal regions are crucial for memory for temporal context (McAndrews & Milner,1991; Milner et al.,1991; Kesner et al.,1994) or unnecessary (Kopelman,1989; Parkin et al.,1993; Parkin & Hunkin,1993). Hunkin & Parkin (1993) suggested that "...both diencephalic *and* frontal lobe damage may impair the processing of contextual information, but...the stages at which they induce impairment may differ..." (p.497). Thalamo-frontal circuits may undertake initial encoding of temporal and other contextual features which are subsequently integrated

and consolidated by the hippocampal system (Parkin & Leng,1993). However, JW displayed intact medial temporal and diencephalic structures but still had difficulties with temporally-organised recall. This is more in keeping with the proposal that the frontal regions perform a cognitive-organisational strategy needed for reconstructing memories (Bowers et al., 1988), in contrast to an initial process of automatic time-tagging of new information subsumed by medial temporal regions.

The orbital emphasis of JW's lesion also raises questions about possible basal forebrain damage which Damasio et al. (1985) suggested may cause impaired strategic retrieval in memory (though see Irle et al.,(1992) for a view on the critical role of the striatum). However, the memory deficits after basal forebrain lesions are often more apparent on formal testing than was the case with JW, and frontal signs are usually secondary (Morris et al.,1992).

In contrast, JW showed primary dysexecutive problems which compromised strategic deployment of memory skills in functional contexts. It is noteworthy that Shallice and Burgess (1991) also reported one strategy application disorder patient with "memory problems secondary to frontal difficulties" and all three of their cases performed relatively poorly on the subject-ordered memory task which is sensitive to frontal lesions (Petrides & Milner,1982). From a cognitive perspective this tends to suggest a model of frontal strategic processes as necessary for retrieving temporal context (Shallice,1988; Parkin et al.,1993; Hanley et al.,1994). Neurologically, these observations support the notion of a baso-lateral limbic memory circuit (von Cramon,1992) anatomically distinct from the orbito-frontal regions which are more commonly associated with "purer" strategy application deficits.

The fact that JW showed mild anterograde memory difficulties on recall and recognition memory tasks may be attributable to the location of her olfactory groove tumour (and surrounding oedema) near to the basal-limbic memory pathways. The full extent of her memory difficulties was only revealed on memory tasks sensitive to strategic retrieval in multiple subgoal situations, consistent with the primary orbito-frontal emphasis of the tumour. Moscovitch (1989) originally suggested that associatively-retrieved memories may be disturbed by medial temporal and posterior brain lesions, whereas strategic retrieval is more vulnerable to frontal lobe damage. Evidence from JW and other cases of strategy application disorder together with reports of basal forebrain-limbic amnesia permits speculation about a processing continuum utilising structurally distinct orbito-frontal and baso-limbic subsystems to varying degrees in which processing of temporal context information is central. This leads to a prediction of a clinical spectrum of orbito-basal-subcortical functioning by which processing becomes increasingly strategy-based and less purely memory-based with increasing anterior (especially orbital) pathology. In terms of temporal information processing, the resulting impairments would be less focused on memory for time and increasingly apparent in poor awareness of temporal passage.

In summary, JW suffered extensive strategy application difficulties which only really became apparent on the demanding Multiple Errands task. It seems plausible that her impairment of prospective and reconstructive memory processes may be viewed as part of a more general disorder of strategy application, a primary deficit within which appears to be poor temporal regulation of behaviour in functional contexts.

13.3 (iii) Strategy application disorder and psychological time

One further issue is worthy of note, concerning the selectivity of strategy application disorder (SAD) as a syndrome. The argument presented in this chapter is that strategy

application disorder is an example of the manifestation of poor temporal regulation of behaviour in functional contexts. Other deficits in temporal awareness may be more evident in orientation (chapter 10), anterograde memory (chapter 9), autobiographical recall (chapter 8) or attentional disruption (chapters 6 and 7). On this basis however, there is nothing essentially different between the aspects of SAD which suggest temporal processing problems (ie. prospective memory) and other disorders of psychological time explored in previous chapters. Both include signs of poor appreciation of time in one form or another, SAD just reflects the deficit as it presents in functional settings. However, SAD has been proposed as a specific dysfunction in prospective remembering arising from orbito-frontal pathology (Shallice & Burgess,1991; Burgess & Shallice,1997) rather than one pole of a continuum of problem solving deficits.

The discontinuity of SAD and other frontal functions implicit in previous accounts of the disorder is brought into question by JW. In addition, the results cast doubt on the notion of SAD as a selective impairment in prospective remembering. In terms of mnestic processes, the evidence strongly supports the view that generic retrieval processes may be involved in both autobiographical recollection and prospective remembering (Williams et al.,1996). In a patient with circumscribed frontal damage such as JW, this produces a profile of apparently intact retrospective memory processes as assessed on anterograde recognition memory and recall tasks, in the context of poor autobiographical and prospective memory.

The notion that SAD may be a selective and dissociable executive disorder is suggested by the primarily orbito-frontal emphasis of the pathology in the reported cases. This implies that not only may strategy application problems occur in the absence of deficits on formal testing, but that cases could be observed to show the opposing dissociation of frontal signs on more traditional tests but satisfactory performance in functional

evaluations. However, many frontal tasks may be sensitive to global cognitive capability such that low intellectual capability may compromise performance. Conversely, high levels of intellectual functioning may mask frontal dysfunction in all but the most exacting of assessment situations. To date SAD has only been demonstrated in patients of superior intellectual ability, raising the suggestion that people nearer the average range of ability, who show deficits on standard frontal tasks may also exhibit SAD. The present case of a patient of low average intellect demonstrates an association of SAD with poor performance on other frontal tasks. The critical issue is whether this is solely as a result of prefrontal dysfunction extending beyond the orbito-basal cortex and possibly involving multiple frontal systems, or whether the results can be better explained in terms of continuity of frontal functions based on task demands.

One reason for the absence of impairment on a number of standard frontal-sensitive tasks amongst SAD patients may be the superior intellectual ability of previous cases. This could be explained by both the discontinuity hypothesis and by a continuum of task difficulty model, with the more formal, constrained tasks being insufficiently demanding for high IQ patients. In fact, difficulties on more traditional frontal tasks have been reported in some cases of SAD, for proverb interpretation (Goldstein et al.,1993), alternating movements and Trail making tasks (Shallice & Burgess, 1991) although in lesser degree than was apparent for JW. These results are exactly as the continuity model would predict on the basis of the intellectual capability of the reported patients.

The MRI scans of JW show involvement of inferior and medial frontal cortex as did the post-lobectomy MRI scan reported by Goldstein et al. (1993) on their SAD case. There was also evidence of fairly widespread structural damage in the original patients reported by Shallice and Burgess (1991) showing "extensive bifrontal damage" [case 1], "extensive low attenuation in the area of the right frontal lobe and marked local atrophy

of the right medial insular cortex" [case 2], and an "extensive lesion to the left frontal lobe with atrophy...also atrophy in the left temporal lobe," [case 3]. JW is therefore similar to previous SAD cases in that all have sustained extensive frontal damage though the emphasis of the pathology lies within the orbito-frontal region, confirming that involvement of the orbito-frontal area would seem to be necessary for the onset of SAD although no reports have demonstrated unequivocally that it is sufficient and produces a selective deficit.

Although the notion of SAD as a qualitatively distinct disorder cannot yet be refuted, it remains in need of support of two kinds. Firstly, it needs evidence of a double dissociation of SAD and frontal functioning controlled for intelligence. Secondly, a convincing case of a circumscribed orbito-frontal lesion producing SAD is awaited. By contrast, the extensive involvement of frontal areas in reported cases of SAD and the difficulties on other frontal tasks shown even by high IQ patients suggests that in practice at least, SAD does not occur as a selective deficit. The alternative thesis, suggested by the results from JW, is that Strategy Application Disorder is qualitatively similar to other problem solving sequelae of frontal lobe pathology, and (as far as mnestic processes are concerned) illustrates one aspect of deficient complex retrieval context. The resulting disability is in keeping with the thesis that problems in temporal regulation of behaviour are the functional aspect of a range of deficits associated with impaired processing of temporal context information.

Chapter 14

Psychological Time after severe brain injury:
Towards a conceptual framework

14.1 Introduction

The purpose of the thesis (as stated in the general introduction, chapter 1) was to investigate the experience of time in terms of cognitive and other approaches, with particular regard to the neuropsychological sequelae of severe brain injury. As discussed in chapter 1, the concept of 'psychological time' encompasses many different but inter-related aspects, disruption to which can produce a range of problems in the temporal organisation of behaviour in everyday life. Yet the lack of any coherent theoretical account of time experience has inevitably hampered investigation of anomalous phenomena associated with brain injury. In this final chapter, following the structure introduced in chapter 3, the evidence pertaining to disparate aspects of psychological time is reviewed in terms of the contribution of attention, memory and executive functions. Unavoidably, in such an exploratory set of studies, many more questions are raised than are answered but several promising areas of investigation are identified and some important revisions to current theoretical approaches are proposed. In the light of the empirical evidence, an argument first presented in chapter 1 is revisited, emphasising the need to recognise multiple perspectives to psychological time.

14.2 The cognitive basis of psychological time

14.2 (i) The influence of attention

In chapter 2 it was recounted that attentional processes are responsible for the everyday sense of time passing more quickly during an absorbing activity (see also Michon,1984; Block,1992). This phenomenon has been widely replicated experimentally (Glicksohn et al.,1991; Grondin & Macar,1992; Brown et al.,1992; Casini et al.,1992) and has given rise to views of psychological time as the outcome of a competitive process between

attention to task and attention to temporal information (Norman,1969; Thomas & Weaver,1975). The mediation of prospective duration by attentional factors is recognised in both internal clock models (Thomas & Cantor,1978) and cognitive accounts such as those by Jackson (1990) and Boltz (1991). This basic premise underlies what may be termed the 'first-order' attentional account of temporal experience which was examined in section 2 on attention and psychological time. From these studies several important issues arose which highlight significant limitations in the current attentional model of experienced time. These are discussed in the next section, but first the general pattern of results will be presented

General results of investigations into experienced duration

In this section two key issues will be addressed pertaining first, to the time estimation accuracy of controls in relation to interval duration, and then to the sensitivity of the tasks to head injury. Using the theoretical framework introduced in chapter 3, it will be argued that at most only two studies might be interpretable within a resource-loss account of timing after brain injury. Instead, the most common or standard results profile suggests the involvement of additional cognitive systems affecting timing ability, especially amongst the most severely head injured subjects.

One way of examining the effect that task duration may have on timing judgements is by equating timing accuracy (theta values) with interval duration. Inevitably, for the studies reported in the thesis it is difficult to draw conclusions about time experience purely on the basis of interval duration because the nature of the tasks themselves varied so much. However, any suggestion of a relationship between time estimation accuracy and actual duration would be extremely interesting, given the many potentially confounding factors which could operate. Therefore, by way of exploratory analysis, for those tasks which were without interruptions and which were prospectively estimated (ie. those reported in chapters 4, 5, 6, and 7), mean theta values for each subject on each task were plotted against task duration. Figure 14.5 below demonstrates this effect for all subjects across the range of durations covered by each task.
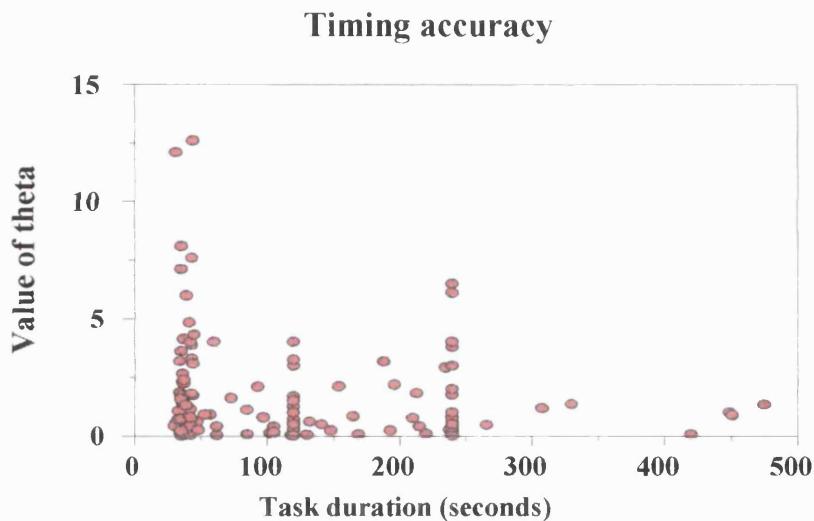
Figure 14.1 Timing accuracy plotted against task duration for all subjects across tasks

Visual analysis suggests that there may be a significant effect of task duration upon timing accuracy but this may be confounded by differences between subject groups. However, there still appeared to be a relationship between timing accuracy and task duration when the raw data were plotted separately for controls subjects (figure 14.2 below) and head injured participants (figure 14.3 overleaf).
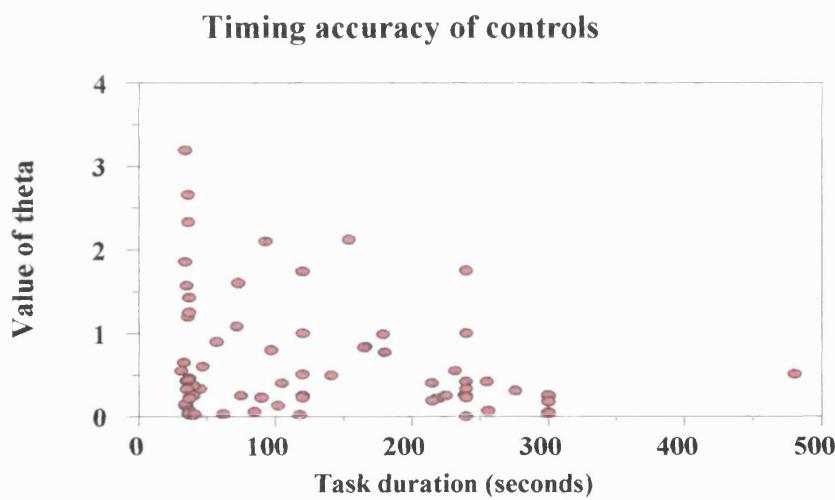
Figure 14.2 Timing accuracy plotted against task duration for control subjects

Timing accuracy after head injury
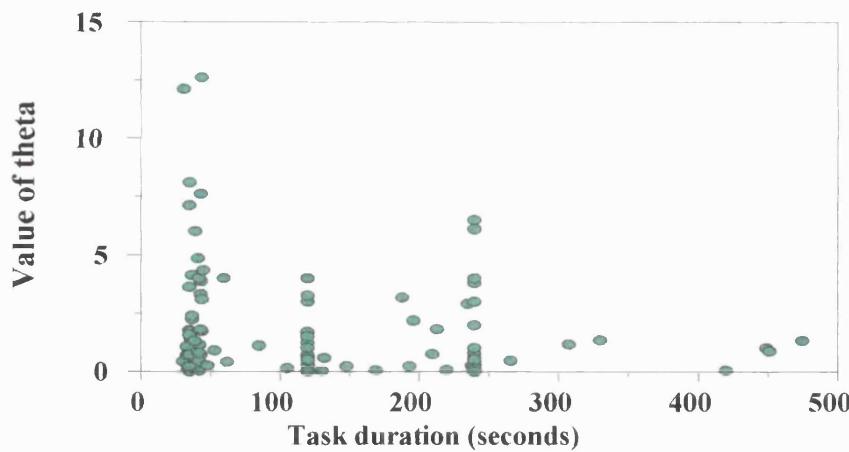
Figure 14.3 Timing accuracy plotted against task duration for head injured subjects

The data were therefore subject to quantitative analysis, comparing theta values obtained by each control subject on each task according to task duration. Statistically there is a significant indication that theta values are inversely related to task length (F = 3.35, (1,71) $p < .001$), indicating that there is a positive relation between timing accuracy and duration. This can be summarised in terms of a mathematical relationship of the kind, θ = k - x . t, where timing accuracy θ is a constant k minus a multiplier x of the task duration t:

$$\theta = 0.756 - 0.0013 . t$$

This relationship is illustrated in figure 14.4 below, showing mean theta values across subjects together with 95% confidence intervals. The results suggest that within intervals ranging from 30 seconds to five minutes, timing accuracy *increases* with longer task intervals. The same effect is also found when all head injured subjects are considered together (F = 10.59, (1,151) $p < .001$), as shown in figure 14.5 overleaf. With head injured subjects the relationship is characterised by the formula:

$$\theta = 1.98 - 0.0036 . t$$

Timing accuracy by task duration
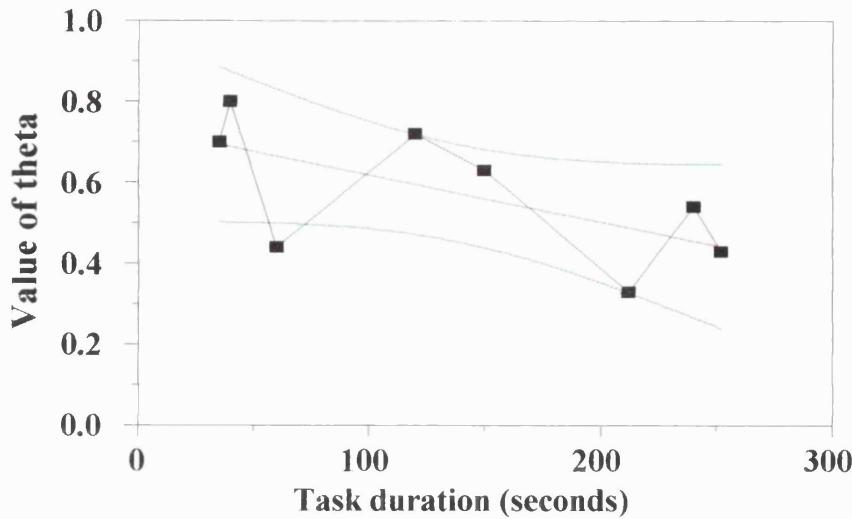
Figure 14.4 Linear regression plot of the relation between time
estimation accuracy and task duration for controls.

Timing accuracy by task duration
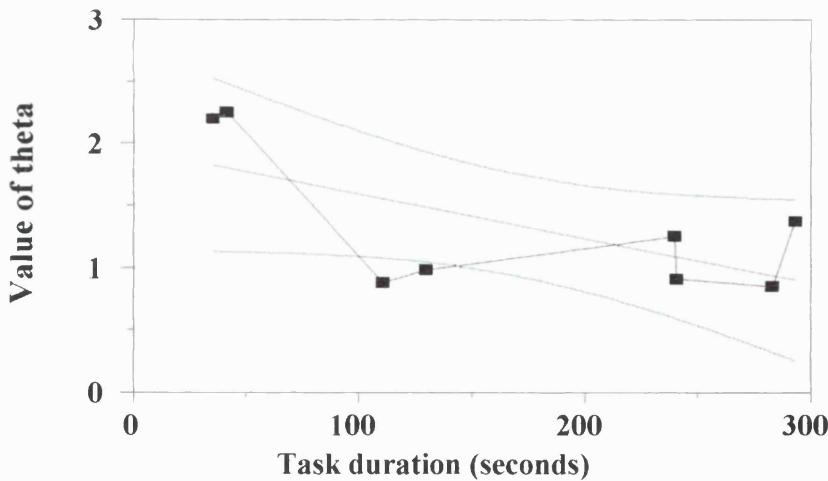
Figure 14.5 Linear regression plot of the relation between time
estimation accuracy and task duration for head injured subjects.

If one examines the two head injured groups separately, then it becomes apparent that the performance of the severe head injury sample does not conform to this relationship between accuracy and duration.   Thus, although mean timing accuracy amongst the severe head injury group is less accurate than that of controls for any specific task duration (cf. figure 14.4 with 14.6 below), their judgements of duration fit a linear pattern where accuracy of estimated time is fairly independent of task duration ($F = 0.47$, $(1,84)\ p > .5$):

$$\theta = 1.0 - .0007 . t$$

In contrast, the performance of the very severe head injury group shows a clear relationship between duration and timing accuracy, consistent with that shown by the controls but of greater magnitude ($F = 16.61\ (1,77)\ p < .001$).   This relationship is illustrated figure 14.7 below and is characterised by the formula:

$$\theta = 3.4 - .0074 . t$$

Timing accuracy by task duration
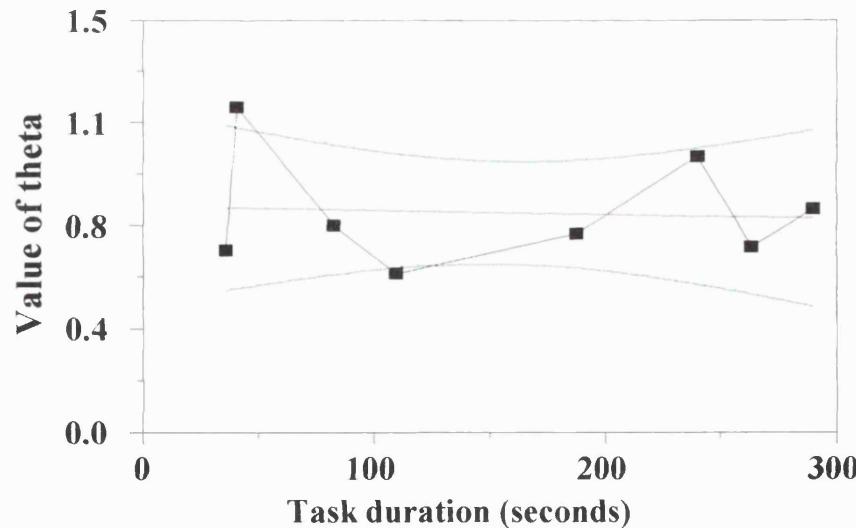
Figure 14.6 Linear regression plot of the relation between time estimation accuracy and task duration for severely head injured subjects

Timing accuracy by task duration
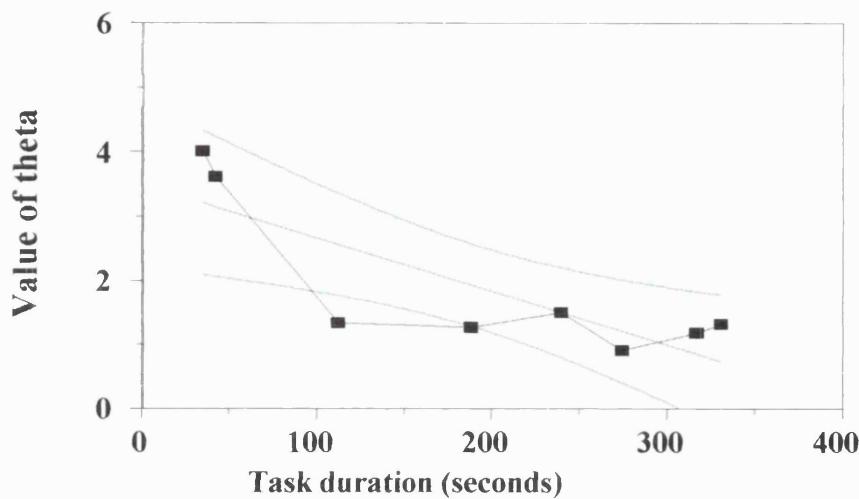
Figure 14.7 Linear regression plot of the relation between time estimation accuracy and task duration for very severely head injured subjects.

More detailed examination of individual tasks where large standard deviations were evident (eg. the recency memory tasks in chapter 4) showed that in general, the relationship between increasing accuracy over longer durations holds up well. This is demonstrated by the severe head injury group too on some specific tasks (eg. the verbal recency memory task) despite no apparent effect of duration on timing in this group over all tasks. This phenomenon of increasing accuracy with longer duration also suggests that studies which do not standardise the interval to be estimated may be liable to type II errors. For example, in chapter 7 the more severely injured subjects took significantly longer than other subjects to complete the card sorting tasks, and could have yielded a lower theta value for this reason alone, thereby obscuring potentially significant differences in timing accuracy had the task duration been equal across the groups.

In summary then, the above results demonstrate that control subjects make significantly more accurate judgements of task length with increasing task duration. This is an important preliminary finding which has not been systematically observed previously. Although a negative linear relationship between task complexity and task duration is an established finding for prospectively estimated tasks (Zakay,1990) the only previous reports relating timing accuracy and interval length have been conducted with animals, over much shorter durations using very different methods (Nichelli,1996). Interestingly, the head injured subjects as a group also show this effect (figures 14.3 and 14.5), though when examined separately it is only apparent for the more severely injured group. It is unclear why the severe head injured group do not also show this effect, but both groups of brain injured participants are generally less accurate than controls (hence the larger intercept value in the regression formulae) and show greater variability across tasks.

The discussion now turns to consider the second principal issue concerning attention and psychological time, namely how time experience varies according to task demands. Many of the experiments conformed to a similar pattern which can be considered the standard with respect to the effects of task demands on concurrent timing. This standard profile will be discussed first then exceptions will be highlighted. Finally, some attempt will be made at interpreting these different outcomes.

As far as the control subjects are concerned, the results from previous chapters suggested that they were fairly impervious to the experimental manipulations that were employed. For example, in chapter 6 the introduction of periodic interruptions to the lexical decision and information processing tasks did not significantly disturb the timing accuracy of the controls. Moreover, when the information processing demands were made more complex there was again no significant effect upon timing accuracy amongst the controls. Hence the errorless version of the lexical decision task in chapter 6 was compared with the errorful version, which might have been expected to be more difficult by virtue of the fact that it involved more careful scrutiny of the stimulus words. However, the durations of the two tasks were estimated with comparable accuracy by the control subjects.

Likewise, though there is a marginal reduction in control accuracy on the complex card sorting task in chapter 7 compared to the simple sort version (see figure 7.3), this is not statistically reliable. The performance of the two head injury groups across tasks is more complicated and, in the light of the exploratory nature of the studies, any speculations will need to be corroborated by further research. Nevertheless, notwithstanding the fact that timing accuracy is generally poorer for tasks of shorter durations, there are some interesting comparisons of head injury performance.
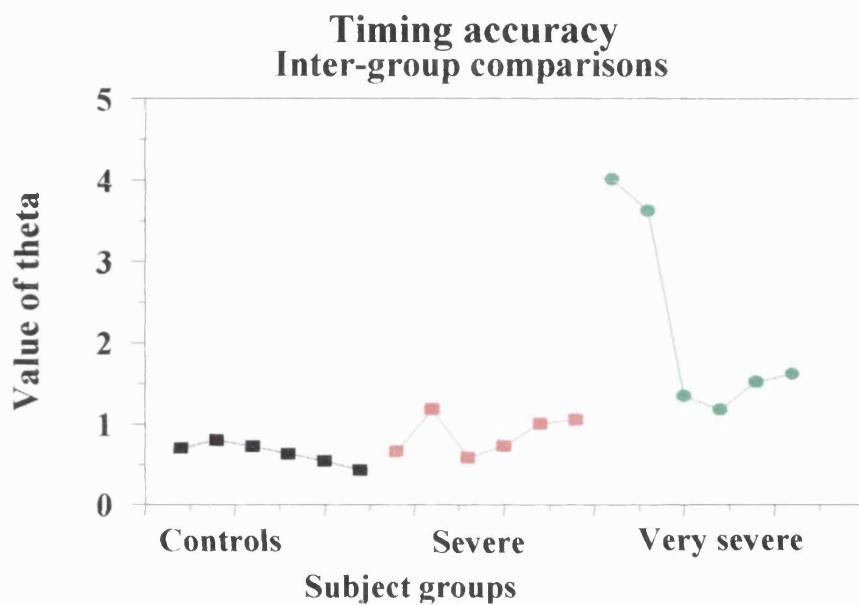
Figure 14.8 Comparison of timing accuracy across subject groups. Tasks are, in order: AH and PW stories (chapter 5); non error and errorful lexical decision (chapter 6); information processing (chapter 6); and complex card sorting (chapter7).

Many investigations produced data which showed significant timing differences between the severe and very severe head injury groups, in the absence of any significant disparity between the controls and the head injured subjects as a whole. This possible outcome was discussed in chapter 3 and is depicted figure 3.1. It is interesting to compare the conceptual model illustrated in figure 3.1d with the actual data shown in figure 14.8 above. This demonstrates the mean timing accuracy values for each subject group across

task durations and provides a good approximation to the hypothetical illustration in the earlier figure.

One possible confounding bias could have been was caused by a tendency for any group (especially the very severely head injured group) to give similar verbal estimates of time regardless of actual task duration. This would have resulted in apparent changes in time estimation accuracy over different durations. To examine this possibility the verbal estimates of subjects were compared for tasks of three specified durations (35 seconds: AH/PW stories in chapter 5; two minutes: error-free lexical decision task in chapter 6; and four minutes: uninterrupted information processing task also in chapter 6). As the illustration in figure 14.9 shows, all groups responded to increases in task duration with a tendency to produce larger estimates elapsed time. Even the very severely injured group demonstrated an effect of environmental conditions upon their subjective awareness of time.
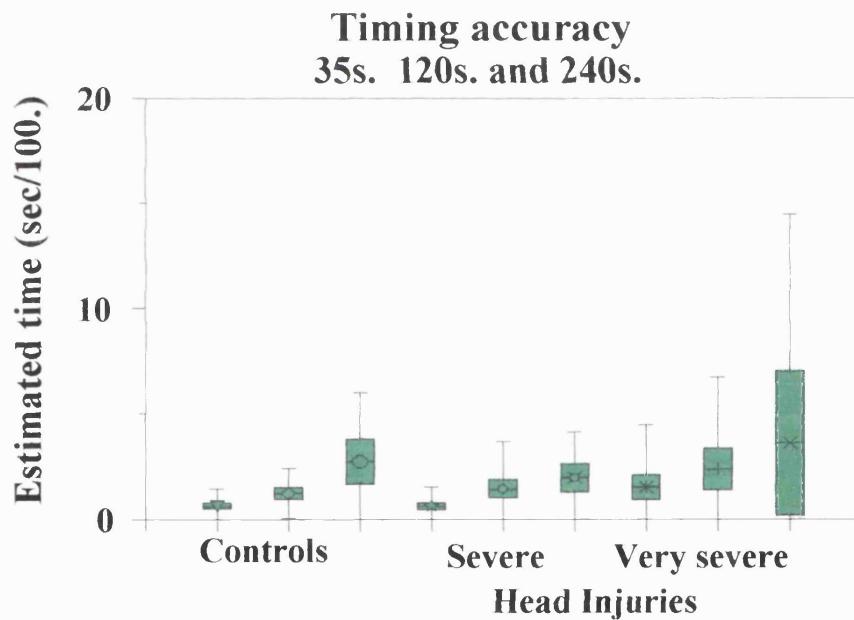
Figure 14.9 Comparison of prospective verbal estimations of time produced by subjects across three specified intervals of time.

In fact, not only is the overall profile of results shown in figure 14.8 inexplicable solely in terms of response bias, but this pattern is evident across the range of time intervals sampled in the research. In chapter 5 for example, there were marked differences between the two head injured groups, though the severe injury group performed comparably to the controls. Similar results were demonstrated by the errorless lexical decision task in chapter 6, on which the only differences in timing accuracy were evident between the two head injury groups. A trend in the same direction was apparent in the error version of the task (figure 6.1), and even more strongly in the interrupted lexical decision task. A trend towards the same effect was also reported in the complex card sorting task in chapter 7.

This repeated observation of a significant disparity in timing amongst the head injured groups in spite of no differences between head injured and controls occurred even when other neuropsychological indices showed differences between the controls and brain injured. The clearest example of this occurs in chapter 5 (the two auditory-verbal narratives) where there is a significant linear trend across the three groups on prose recall, in the context of a categorical differences in timing accuracy between the two head injured groups.

Having reviewed the most characteristic outcome of the time estimation studies, it remains to consider the exceptions to this general trend. Of all the time estimation studies reported two yielded results which might more plausibly be interpreted in terms of resource loss after head injury. These were the interrupted information processing task in chapter 6 and the simple card sorting task in chapter 7. In the latter task the completion times showed a linear trend, with further trends evident between controls and the two head injury groups with respect to accuracy of time estimation. However, such was the variability in responses provided by the head injured subject that these discrepancies did not reach significance. Therefore they must remain at most suggestive of resource loss effects after head injury.

In contrast, the interrupted information processing task in chapter 6 elicited significantly more accurate timing from the controls than the head injured subjects. There was also a trend towards greater inaccuracy amongst the very severe head injury group, as one would expect with a resource loss, but this discrepancy was not significant. In terms of duration the four minutes which this task lasted was in the middle of the range of intervals sampled in the research, but the task itself was complicated by the periodic interruptions from a timer. Qualitatively, interrupted tasks seemed more difficult for head injured subjects and, as this was the longest of the interrupted tasks employed, it seems reasonable to presume that this task too was amongst the most difficult of all those investigated. Following this reasoning, the obtained results would seem to provide further support to the suggestion that the most demanding of information processing tasks were those which were most likely to be sensitive to general resource losses after brain injury. Hence these tasks were especially sensitive in discriminating between head injured subjects and non head injured controls.

If the data on prospective time estimation after head injury cannot readily be explained in terms of general loss of resources, one has to consider whether there is a plausible alternative account. It may be speculated that time estimation places particular demands on a range of cognitive systems and it may not be disrupted to the same extent as other processes in any given interval. In particular, short durations, such as those employed in chapter 5, may be especially sensitive to deficiencies in attentional, memory or executive functioning, hence the timing discrepancies between the two head injury groups were most marked on this, the shortest task. As stated in the discussion in chapter 5, to interpret this pattern in terms of general resource losses requires an assumption of non-linearity between performance and resources which is difficult to entertain given the magnitude of the difference in timing between the two head injury samples. A more plausible account may be fashioned in term of the involvement of additional cognitive subsystems in the very severe brain injured group.

It seems possible then that the overall pattern of results from studies on experienced (ie. prospectively estimated) time are compatible with the greater involvement of specific subsystems of cognition amongst the most severely brain damaged subjects. This general pattern was also observed in tasks utilising methodologies different from those which have formed the basis of the discussion to this point, namely the time production information processing task in chapter 6, (with the two head injury groups showing differences in significant timing) and the retrospective estimation method employed in chapter 10. In view of this corroborative evidence the pattern depicted in figure 14.6 seems unlikely to be an artefact of the prospective verbal estimation method used in the majority of the studies. The most plausible alternative account seems to be that the most severely disabled group of subjects have sustained more extensive damage to executive subsystems which is likely to underlie the extreme disturbances of self-awareness and orientation which they suffered.

Problems with the attentional model of Psychological Time

Having reviewed the principal features from the main body of experimental studies, three specific concerns can now be raised about current conceptions of the role of attention and psychological time. First, there is the rather vague and unspecified notion of temporal information or what exactly constitutes the 'temporal attribute' (Jackson,1990). In everyday situations increased attention to a variety of factors could result in less accurate and possibly shorter estimates of interval duration. Therefore any number of different variables might qualify as temporal information depending on the circumstances. The second criticism pertains to assumptions about how subjects carry out concurrent timing tasks. The standard account is predicated on the basis that a person's behaviour during a task (ie. their measurable performance) reflects their cognitive strategy, so that if timing ability deteriorates, that individual is presumed to be struggling with the principal task demands and has recruited more attention to task. As Hockey (1993) notes: "the widespread phenomenon of attentional narrowing...may be seen as a general strategy for reducing attentional demands under stressful conditions...." (p.333). This approach to what is known as 'strategic adjustment' has been universally accepted in timing studies

with normative samples (eg. Thomas & Cantor,1975; Hicks et al.,1976; Casini et al.,1992) but may be a somewhat naive assumption to make for clinical groups, as the discussion below will make clear. Finally, the first-order attentional theory is generally couched in terms of producing varying degrees of temporal underestimation depending on how engrossed a person is with a task (Grondin & Macar,1992; Casini et al.,1992). Although seldom made explicit, the implication here is that without corollary task demands timing would be pretty accurate. Consequently, there is no conceptual basis for predicting overestimation of duration and no appreciation of the relevance of considering timing accuracy as a whole, regardless of the direction of estimation bias. The evidence relevant to each of these issues is reviewed below.

The notion of temporal information

Several studies relevant to the debate as to what constitutes temporal information were reported in chapters 4 to 7. In chapter 4, there was no suggestion from the recency memory tasks that order information had any privileged status as a basis for inferring duration. Although no selective recency memory deficits were elicited in this study, verbal recognition memory and recency judgements were not correlated and yet timing accuracy was not more strongly associated with one than the other. The data from this chapter are rather weak but the results suggest that attention to this form of temporal context is not critical for a sense of duration. Indeed, there are grounds for suggesting that memory for temporal relations between events in a sequence requires effortful processing (Estes,1984), in which case the expected outcome would be an inverse relationship between order and duration.

In contrast to the somewhat negative results from chapter 4, there was strong evidence reported in chapter 5 that intrinsic temporal structure organisation can facilitate information processing. In general the controls showed better recall of auditory-verbal information and greater timing accuracy than head injured subjects. The amount of information recalled was also sensitive to the severity of brain injury, with very severely injured subjects performing significantly worse than the severe head injury group. For all

subjects greater temporal coherence in narrative organisation was associated with improved story recall. However, greater information retention did not directly affect prospective timing accuracy as the two head injury groups showed marked differences from one another in this respect whilst showing consistent intra-group time estimation across tasks (see figures 5.1 and 5.2). The data therefore suggest that temporal organisation can facilitate information retention, but that this does not produce more accurate prospective timing. This result contrasts with signs that such structurally-enhanced memory for interval content can facilitate retrospective timing (Berg,1979; Mulligan & Schiffman,1979), probably because different mechanisms are involved in attention to time and in auditory-verbal recall. A similar conclusion was reached by Zakay et al., (1994) who indicated that manipulations which may directly improve memory for information do not necessarily increase prospective timing accuracy. Nonetheless the results suggest that events do have an intrinsic temporal structure to which information processing systems, especially those damaged in some way, appear to be sensitive.

When tasks are interrupted periodically one might surmise that the temporal structure of an event is disturbed, and therefore that timing may be affected. Certainly in chapter 6, the most significant discrepancies in timing between subject groups were obtained in the interrupted information processing task (see figure 6.4). This was the only task to discriminate significantly between controls and head injured subjects. Interrupted tasks may be particularly sensitive to attentional deficiencies after head injury and therefore more likely to reveal disturbances in concurrent temporal monitoring. However, on conceptual grounds alone the response triggered by the task interruption in chapter 6 may have been inadequate to interfere with the primary task, disturb on-line action schemata and produce a readjustment of cognitive strategy. In other words, the timer could be switched off by a simple motor response akin to unmodulated contention scheduling (Shallice & Burgess,1993) or relatively automatically (Jacoby et al.,1993). Hence only the longer of the two interrupted tasks revealed performance discrepancies and then only between the two head injury groups. One explanation is that subjective experience of

duration tapped by time estimation cannot be modified by lower-level representation of timing for action necessary for responding to the timer (MacKay,1982), but this sustains a functional schism between motor timing and subjective experience which current models are trying to bridge (Vidal et al.,1992; Day,1996; Pastor & Artieda,1996).

In fact, when the interruptions were made intrinsic to the task, as they were in the card sorting test in chapter 7 then both control and head injured subjects showed a marginal tendency ($p < .2$) towards reduced timing accuracy with more complex task demands (figure 7.3). The reason why these effects were not stronger may lie not so much with the size of the sample (as discussed in chapter 7) but more with the study design, and in particular the fact that there was no stipulation for the tasks to be completed within time limits.

To explain this further: it seems reasonable to assume that there are two ways in which individuals can respond to increases in task demands. One manner is to complete the more complex task in more or less the same amount of time, but somewhat inevitably at the expense of a corollary task such as time estimation. Even though subjects were given as much time as they needed, this appears to have been what the control group did. Alternatively, without time restrictions one can devote additional time to the more complex task, a strategy which would not necessarily involve any reduction in timing accuracy because it does not require extra attention to be allocated to task demands within a given time limit. The controls took a similar time to complete both sorting tasks and, not surprisingly on this basis, there were signs of a slight cost in terms of timing. In contrast, it seems plausible that the head injured subjects found the complex sorting task much more difficult than the simple sorting version, and in the absence of time constraints they inevitably took much longer to complete it. This strategy does not entail the same trade-off between task performance and timing which is involved when task demands change within a time limit. Thus the failure to demonstrate significant differences in timing as a result of changes in task demands can be interpreted as a consequence of the likely differences in information processing strategy employed by the

controls and head injured subjects. Given this argument, the obtained results are not in conflict with an attentional account of psychological time.

In general these data shed some light on the kinds of task variables which affect timing. Clearly, individuals with a brain injury find it easier to process material that is temporally organised, and there is some suggestion from investigations in chapter 6 that they seem to have greater problems in monitoring task duration when it is periodically interrupted.

The importance of problem solving strategy

Attentional models of psychological time assume that time estimation ability at any given time is proportional to the amount of attention allocated to non-temporal task demands. Thus time is thought to be monotonically related to the weighted average of information encoded by a temporal and a non-temporal information processor operating in parallel (Thomas & Weaver,1975). Whether this kind of simple mathematical formulation is broadly applicable is brought into question by studies with brain injured subjects. When task execution is not always better in the context of poorer timing it raises doubts that inaccurate timing is always indicative of greater attention to task demands. It is therefore inappropriate to use the dependent measure of timing as an index of the independent measure, task difficulty. In future, the kind of strategy subjects engage in needs to be considered (Hogan,1978). For example in chapter 4, subjects showing a floor effect on task performance might be devoting considerable effort to the timing aspect. A similar argument was raised in chapter 7, where it was shown that increases in task demands are not always associated with a reduction in timing accuracy. These results raise further questions about the assessment of time estimation abilities which generally ignore qualitative considerations such as the cognitive strategy subjects adopt. To illustrate this point further, there is some evidence that prospective time estimates vary depending on whether subjects treat the timing aspects of a task as primary or secondary (Zakay & Block,1996). In all the investigations undertaken in the present research subjects were encouraged to conceptualise the timing aspect of a task as a secondary component. This was an attempt to make the tasks more realistic functional analogues as goal-driven

behaviour in everyday contexts is usually evaluated primarily in terms of task completion. In such a context subjects may well adopt strategies which minimise the role of time constraints altogether. For example, in chapter 7 where no time limits were set, head injured subjects in particular responded to the increased demands of the complex sorting task by taking much longer to complete it, with consequently less disturbance on timing ability.

One may surmise that individual strategies to concurrent timing may either be idiosyncratic or a more predictable response in the face of threats to limited general purpose resources such as working memory or attention (Hockey,1993). In clinical studies at least, where the performance of individuals is often judged against the aggregate performance of groups of 'normal' controls (Della Sala & Logie,1998) more information needs to be gathered about how subjects tackle the dual demands of task completion and temporal monitoring. Jackson (1984) has suggested exploring subjects' problem solving with a technique such as verbal protocol analysis. Certainly given the response variability amongst brain injured subjects, the nature of strategy appears to be an important feature in clinical studies. How this is undertaken is clearly an issue for future research. Protocol analysis has been used with brain damaged patients (Goel et al.,1997) but the enterprise is fraught with difficulty. Tsang et al. (1996) noted that subjective reports of strategy deployment even amongst normal samples do not appear to adequately reflect severity of competition for attentional resources.

The relevance of timing accuracy

It is implicit in attentional models of psychological time that duration estimation is normally fairly accurate, but that it can deteriorate given insufficient attention, in which case time is underestimated. This simplistic prediction was established early in the development of attentional approaches to timing and has been uncritically adopted since (Block 1990a; Grondin & Macar,1992; Martinez,1992). Undoubtedly this has been perpetuated by the absence of clinical studies which would otherwise have illustrated the limitations of this approach. The data derived from the clinical studies in section 2 are

almost exclusively reported in terms of accuracy of time estimation. An adjusted time estimation accuracy score was calculated because a ratio of estimated time to actual time which shows the direction of bias is inevitably skewed upwards (because there is a bottom zero but no upper limit). Empirically this also proved sound as all the studies showed great variability in time estimates provided by head injured subjects, especially those most severely damaged. Consequently the differences between controls and experimental subjects were only statistically apparent as differences in timing accuracy. This is also the more clinically meaningful measure, even for those studies which failed to demonstrate statistically significant discrepancies between the groups, as the marked inter-group differences in variance associated with time estimations are not observed in non-clinical studies. These methodological issues raise concerns about the adequacy of data from which are derived current attentional models of psychological time. Certainly two modifications need to be included. First, the notion of temporal underestimation with increased attention to task should be made relative to estimated duration in a similar but less demanding version of a given task, rather than pertaining only to the actual clock duration of an interval. This necessitates that two tasks are always employed in attentional studies, even with normal samples. Secondly, it should be recognised that accuracy of time estimation is the more generalisable index of subjective duration.

In concluding this section on attentional contributions to psychological time, it is worth reviewing the implications for theories about normal time experience. On the basis of the above discussion, any attempt to incorporate the complex data from brain injured subjects requires a revision of the notion of prospective timing as the weighted outcome of the allocation of attention as a limited and fixed resource. The data reviewed above are broadly compatible with a modified attentional concept of time experience. The question is whether they indicate the need for a specific timing device. In chapter 2 it was suggested that the internal clock remains a useful heuristic (Allan,1992) but such models are likely to operate in isolation over limited durations, perhaps only seconds (Ivry & Hazeltine,1992). Revisions of the model appear to be increasingly cognitive nature which raises questions about whether a neural clock mechanism is still relevant.

Zakay and Block (1996), on the basis of a review of a number of animal studies, suggested that a parsimonious cross-species account of temporal awareness can be fashioned from the internal clock mould, made permeable to cognitive mediation, ie. a "cognitive timer." In keeping with comparative data showing that timing in animals appears to be mediated by attention (Meck,1984), Block and Zakay (1992) proposed a modified internal clock incorporating an attentional gate between the pacemaker/calibrator aspect and the accumulator and reference memory stages (see chapter 2 for an elaboration of these components). It was hypothesised that reduced attention to time was associated with a narrowing of the gate, resulting in fewer timing pulses to be registered in the accumulator.

Although not developed on clinical grounds, this hypothesis does have clinical potential and deserves further consideration. For example, if the normal state of the timing mechanism is assumed to be equivalent in control subjects, and if the vagaries of head injury are recognised to produce diverse effects at the level of detailed neuronal functioning, then brain damage would be associated with a range of disruptions to the timing process (eg. irregular emissions from a pulse generator or inconsistent modulation of an attentional gate) with a consequent increase in variability of performance after head injury (see data in chapters 4 to 7). Moreover, it offers a means to appreciate why increased task demands often appear to shorten estimates of task length - greater attention to task would be associated with fewer internally-generated pulses or oscillations being registered in an interval, thus yielding under-estimation of time (see chapter 10, table 10.3).

Despite its initial promise, there are also limitations to the attention-gated timer model so far as the present research is concerned. Perhaps most significantly it does not predict over-estimation of time. Given that the most common effect of neuronal depletion is under-activation of neural systems, the most likely consequence according to the model would be a reduction in pulse rate and therefore under-estimation of duration. However, the importance of an overall measure of accuracy of time estimation was stated in

chapter 4, and where the direction of estimation bias was recorded it is often reflected in overestimation (see chapter 6, tables 6.4 and 6.5). Clearly other factors, reflecting the operation of cognitive systems other than attention must also play a part, and it seems likely that individual factors such as drive, motivation and fatigue also need to be taken into account (Revelle,1993).

The solution may lie within other fields of enquiry which to date have not been applied to the domain of psychological time. For example, Hockey's (1993) model of control and stress regulation, although not concerned with timing, nevertheless provides a useful formulation of the relation between cognitive demand, arousal and compensatory response, which have been identified previously in the discussion as potentially important influences on psychological time. Within Hockey's model two levels of control maintain behavioural stability. The 'routine' control loop contains an action monitor which activates adjustments to behaviour, including timing, if discrepancies between current cognitive activity and target state are detected. Similar systems have been proposed on the basis of neurophysiology (Artieda & Pastor,1996) and brain structure (Pastor & Artieda,1996). However, when an increase in effort requirements is demanded a higher-level supervisory controller is activated, (see also Shallice,1988). According to Hockey (1993) this may result in an increase in effort expended, a modification of task objectives or disengagement from the exercise altogether. Thus there may be a number of means by which adjustments are made to task demands which impact upon timing and it was notable during the many time estimation studies undertaken in the present research that there were signs of all three strategies being used, especially by the head-injured subjects. The utility of Hockey's model is that it can be adopted to provide a preliminary framework for establishing how people carry out concurrent timing in the face of multiple task demands, but so far it is not possible to predict how individuals will respond in any given case. What is needed in the future is research on psychological time embodied firmly within the mainstream of cognitive theory.

14.2 (ii) The role of memory in psychological time

The role of memory in psychological time is complex, involving many different memory systems (Block 1996) contributing to different facets of time experience. The diversity of mnestic influences is reflected in the chapters which comprise section 3 of the thesis. In the following subsections these different contributions of memory to psychological time will be discussed in terms of retrospective memory processes, anterograde memory skills and semantic memory respectively.

Memory for past events and temporal context

It was argued in chapter 3 that temporal context information is critically involved in sustaining retrograde memories, and in particular, that autobiographical life histories help to maintain the integrity of personal identity through time. These assumptions provided the grounds for the detailed investigation in chapter 8 of a case of post-encephalitic retrograde amnesia. SMH showed a severe memory impairment for public and personal events on recognition and recall tasks in the context of relatively preserved memory for the names of familiar people. It was argued in chapter 8 that stored information may usefully be considered in terms of mechanisms of access and retrieval. On this basis it was proposed that the representation of past events, particularly autobiographical incidents, is temporally organised and that this structure provides a framework for episodic retrieval. This formulation is in keeping with proposals that semantic and episodic information differs in the nature of the indexing procedure (Schank,1982) and the retrieval process (Mandler,1980). In addition, temporal indices of mnestic organisation provide a means of specifying descriptors of memory in autobiographical recollection (Burgess & Shallice,1996). As reported in chapter 8 the pattern of SMH's autobiographical memory deficit was consistent with a primary deficit in recollection of information utilising temporally-organised retrieval frameworks

On the basis of this case and the model put forward by Hodges & McCarthy (1995), it seems plausible that past events are stored as time-based representations or 'themes' which are activated in the recall of context-specific information. The data from SMH

suggest that there should be a predictable relationship between the nature of autobiographical material and its accessibility:-

$$pR = f(I_t)$$

such that the probability of successful retrieval (pR) is a function of the degree of which the to-be-recalled information (I) is temporally organised (t). There may well be other 'themes' or levels of organisation in episodic memory but a time-based framework seems quintessential to information processing. For example this simple formula is also consistent with the results reported in chapter 5 showing increased story recall with greater temporal coherence. Furthermore, it seems likely that maintenance of an appropriate temporal context to the contents of current awareness and past experience is critical in providing a sense of continuity to the notion of self and identity (Talland,1965).

The importance of anterograde memory skills

The contribution of memory to psychological time first received widespread experimental support in the form of Ornstein's (1969) early storage-size metaphor (see chapter 2). Since that time the relation between ease of information processing and subsequently shorter remembered duration has been well established (Vroon,1970; Berg,1971; Miller et al.,1978; Hochhaus et al.,1991). It is less clear whether memory for any specific type of information contributes uniquely to this effect although Block (1974; 1978) has argued that remembered duration is based upon memory for change or context rather than memory for individual events. Nevertheless there is little evidence that *temporal* context plays any special role in this effect (Block,1990b). The results from chapter 4 are in keeping with this observation, as memory for temporal order was not more strongly associated with estimated time than was memory for items.

In chapter 10 this issue was investigated further within the terms of Baddeley's (1982) distinction between interactive and independent context. The results showed that recognition memory was sensitive to the presence and severity of brain damage

(consistent with Millis & Dijkers,1993) and that very severely head injured subjects were particularly poor at benefiting from interactive context in making recognition judgements. Estimates of remembered duration from very severely head injured subjects showed characteristically large variability and considerably less accuracy than shown by the severely head injured, with head injured subjects as a whole tending to underestimate the interval duration. This profile of timing accuracy across the groups for remembered duration is consistent with the results from studies of experienced time (figure 14.8). However, retrospectively judged duration was not directly related to overall recognition memory performance or to memory for a particular form of contextual information (consistent with Loftus et al.,1987). Therefore there was no evidence that any particular form of context mediated duration experience. As discussed in chapter 10, the results may have been affected by inefficient encoding of interactive context in head injured subjects (Jacoby et al.,1989). As they stand, the data conflict somewhat with the contextual-change model (chapter 2, section 2.4) which predicts that remembered duration would be related to memory for context rather than target information (see chapter 10). However, Block's account derives most support from evidence of abrupt very explicit changes in task demands rather like the shifts in action schemata in chapters 6 and 7. An obvious follow-up study would therefore be to use task interruptions/conceptual shifts in a retrospective time estimation paradigm. As Block (1990b) has acknowledged, it is difficult to ascertain which specific cognitive processes are involved when a person remembers the amount of contextual change in an interval, but one useful method would be to compare patients with selective frontal and temporal lobe lesions, as has been done for recency memory (McAndrew & Milner,1991) and planning (Morris et al.,1997).

Another important result from the present study is the general tendency for head injured subjects to underestimate time intervals in retrospect as well as prospectively. This is contrary to cognitive theories about psychological time which, following William James, assume a reciprocal relation between attention and memory (see chapter 2). In other words cognitive theories predict that an interval which is remembered as comparatively

long seems to pass quickly at the time, and vice versa. The conflicting observations from head injured subjects that this is not always the case raises doubts about the validity of the purely cognitive 'timing-without-a-timer' accounts. However, as explained above, within a modified internal clock model a tendency to underestimate duration could result from either a reduction in pulses generated by the clock or an impaired reference memory system with fewer events being stored. The greater explanatory potential of the internal clock in accommodating counter-intuitive results such as these is a significant argument in favour of its retention, albeit in modified form, rather than simply explaining psychological time in terms of general information processing systems.

The notion of a modified internal timing mechanism or system was also used in chapter 9 in which the experience of time in relation to severe memory disorder was explored. The results were generally in keeping with previous reports that amnesic subjects may not show marked deficits of time estimation for periods of one to two minutes (Kinsbourne & Hicks,1990; Shaw & Aggleton,1994), although SMH did show a tendency to experience intervals of up to two minutes as passing relatively slowly. This may be a sign of a relatively faster rate of subjective time such as could be produced by a faulty pacemaker or pulse generator in an internal timing mechanism. In contrast SMH was unable to provide valid estimates of time experience for longer periods. Instead formal testing seemed to elicit a response bias, perhaps based on plausibility, though this may have been confounded by reasoning problems which encompassed poor temporal estimation (see section 14.3 below). Clearly, the possibility of such confounding factors needs to be taken very seriously in clinical studies and ideally a non-verbal means of response time estimation (such as the method of time production) should also be included in any future investigations.

Of particular interest in the case of the amnesic and temporally-disoriented SMH is that she retained a knowledge of facts about time and could tell the time, thus demonstrating that aspects of psychological time likely to be subsumed by semantic memory remained well preserved (see next section). Indeed, SMH's impaired awareness of time was in

marked contrast to her ability to perform many daily tasks and regulate her behaviour for specific activities within temporal parameters, suggesting that certain behavioural aspects of timing remained relatively preserved. In other words, her movement timing/quite was normal and the organisation of routine complex action sequences was also entirely satisfactory. Hence ease of task execution does not necessarily facilitate monitoring of time. This suggests that the representation of time in action sequences which may be termed 'procedural timing' is dissociable from conscious experience of time (see also MacKay,1982). Such an inference is consistent with evidence that even in temporally disturbed individuals, estimates of duration may in some sense be primed by prior experience (Paller et al.,1991). In terms of an internal clock it would seem that two processes need to be distinguished on the grounds that the representation of time necessary for the integration of overlearned action sequences does not depend upon attentionally-gated acquisition of pulses or oscillations. The former is likely to involve diverse cerebellar (Clarke et al.,1996), basal ganglia (Pastor & Artieda,1996b) and frontal motor systems whereas conscious awareness of duration seems to require involvement of hippocampal and neocortical regions including the prefrontal area (O'Keefe, 1985; Olton, 1989).

In contrast to SMH's functionally intact timing for set behavioural routines, executed with minimal self-monitoring or conscious mediation, she was very aware of, and had grave difficulties in coming to terms with, her temporal disorientation and memory impairment. This appeared largely to be due to her inability to remember her recent past (for which she had amnesia for both personal semantics and incidents). From a phenomenological perspective it is interesting that she exhibited considerable hostility during the investigations. Although her fronto-temporal pathology might have been expected to produce a propensity to disinhibited acts of agitation, it is nonetheless noteworthy that it was frequently elicited by confrontation with her disorientation in time. It seems plausible that such a deficit in autobiographical memory or temporal awareness is likely to risk undermining the integrity of the sense of Self. Thus phenomenological explorations of time experience need to encompass much more than

the psychological present and consider the role of the representation of the past in giving meaning to the present (Campbell,1994).

The evidence from chapter 9 shows that, although an internal timing process such as a modified neural clock may continue to function after severe brain damage, subjective time experience may be qualitatively different from "normal" time. Clearly, it is not simply based on events or task demands. Instead, the complex cognitive and behavioural sequelae of severe brain injury would appear not only to disrupt attention and memory processes which underlied temporal awareness but also renders individuals more susceptible to distorted reasoning and response biases (see section on executive functions, below). Memory, in particular, plays a vital role in sustaining what Fraisse (1963) termed "temporal horizons." This is clearly illustrated in instances of severe memory disorder in which experience is based on a fleeting sense of the present.[6] The discontinuity of the amnesic state is clearly evident in HM's report that "every day is alone in itself" (Milner et al.,1968). HM also markedly underestimated time intervals (Richards,1973) suggesting that in patients with both retrograde and anterograde amnesia the isolated fragmentary nature of time also encompasses on-going temporal experience. Anecdotal reports suggest that this kind of gross disturbance of psychological time can co-exist with spared temporal faculties such as the ability to tell the time and to recount basic temporal facts. Observations of this nature suggest that semantic memory processes may contribute uniquely to certain aspects of time experience and this formed the basis of the final chapter in section 3 on semantic memory.

Semantic memory and psychological time

In chapter 3 it was proposed that knowledge about time, in the form of conventional temporal units and representations, may be considered to be semantic memory based. Representations about time can have numerical, linguistic and visual aspects. It is well established that brain damage can cause selective impairment in aspects of semantic

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[6] Perhaps the most striking example on record of this experience was the case of a post-encephalitic amnesic whose pre-occupation with a state of "just wakening" persisted for over nine years (Wilson et al.,1995).

memory and, on this basis, knowledge about time might be deficient to the extent that it depends upon certain generic aspects of semantic representation, such as visual semantics, that are known to be disrupted. Nichelli et al., (1993) found that patients with probable Alzheimer's disease of mild to moderate severity experienced more extensive impairment of time estimation than purely amnesic patients which suggested some additional contribution of semantic memory and executive dysfunction to disturbance of psychological time in the dementia cases. However, the cognitive processes in the ability to interpret time and its relation to action remain largely unknown. It is entirely plausible that knowledge about time has certain unique attributes which cannot be subsumed by numerical and visual processes. Therefore the investigations undertaken in chapter 11 are particularly interesting as they provided evidence which is very much in keeping with current efforts to examine autobiographical contributions to semantic memory (eg. Snowden et al.,1996). The data from chapter 11 suggest not only a means by which temporal notations are interpreted but also how this information may be reciprocally related to experience about events.

Conventional standards of time can be represented in separate analogue and digital formats, comprehension of which can be selectively undermined by modality-specific deficits (see cases AS and DG in chapter 11). However, other data, in particular that derived from DC and VF who had diffuse brain damage, also suggested that analogue and digital forms of temporal representation are at least partially separable from their constituent numerical and perceptual components. It was proposed that transcoding between analogue and digital notation entails a dual-stage process, the first stage of which is *recognition* of the temporal code. This is hypothesised to depend on a appreciation of a rule-governed clock-reading grammar. A second process of *translation* is then responsible for effecting the production of a semantically equivalent time in another notation.

Mindful that numerical processing models have become somewhat sidetracked with syntactic preoccupations at the expense of meaning (Dehaene,1992), it is important to

stress that the importance of being able to understand digital time is not to translate it into analogue mode, but to be able to use the information to modify behaviour (Freyd,1992). It was speculated that temporal codes, by virtue of their association with actions, have semantic links (time-action relations) which may be specific and idiosyncratic, as indeed they can be with other supposedly context-independent facts such as numbers (Cohen et al.,1994) and names (Snowden et al.,1994). Certainly all four subjects were able to state reasonable clock times corresponding to the performance of a number of common daily activities as well as showing satisfactory access to basic facts about temporal units. Knowledge about time, as a domain of semantic memory, therefore has two time-specific aspects. This incorporates a context independent store of temporal facts which is necessary for proper appreciation of a clock reading grammar, and a repository of associations of action and duration which provides the basis for time estimation and reasoning necessary for timely behavioural regulation (see next section).

14.2 (iii) The contribution of executive skills

Virtually all current accounts of time experience have been derived from experimental studies which have a clearly defined structure with start and end points and explicit goals. Such designs are not likely to be sensitive to the functioning of executive control processes which operate in the less constrained real world of temporal experience (eg. De Keyser,1990). Consequently the attentional and memory based models of time reviewed in chapter 2 are likely to be flawed in respect of how behaviour is temporally organised in everyday contexts. Similarly, in the clinical literature on dysexecutive problems, the importance of time-based control processes is only just starting to be appreciated (Fuster,1985; Milner et al.,1985; Burgess & Shallice,1997). However, if accurate time experience is crucial to efficient behavioural regulation, no clinically meaningful account of psychological time can be formulated without due consideration of the role of executive skills. For example, Zakay (1992) noted that attention to time in problem solving depends on the perceived relevance of time constraints to the task. Furthermore, the kinds of situation where attention is diverted away from temporal monitoring are just those which Shallice and Burgess (1991b) identified as being necessary for the operation

of the supervisory attentional system. Yet changes in cognitive strategy which could undermine task performance, timing or both are most likely to occur in response to the need to protect limited attentional resources (Hockey,1993). These concerns formed the impetus for the studies reported in section 4. In essence chapters 12 and 13 in this section address two different issues: the former investigates how distortions or biases in time estimation studies may arise, and the latter examines the role of temporal information processing in everyday problem solving.

Dysexecutive influences on Psychological Time

A key observation which indicates the relevance of problem solving skills to time estimation studies was reported in chapter 12. It was demonstrated that severe head injury is associated with poor ability to make 'cognitive estimates' (Shallice & Evans,1978) and that judgements about the durations of fairly familiar tasks appear to be particularly sensitive to this type of reasoning difficulty. There are two implications to this result, for understanding executive aspects of psychological time and for appreciating potential confounding factors in experimental studies. Firstly, given the importance of time-based aspects of everyday problem solving, deficits in this form of temporal reasoning could significantly undermine the temporal organisation of action in functional situations.

In addition, the data elicited in chapter 12 and previous chapters provide grounds for caution in the interpretation of studies which rely solely on verbal estimation as a means of response, as brain injury may be associated with an increased vulnerability to response distortion. To the extent that individuals are rarely required to estimate verbally the duration of an interval in everyday contexts, prospective timing tasks could be considered novel problems for which there is no readily available knowledge or plan. Shallice and Evans (1978) identified such instances as those most likely to highlight deficiencies in 'cognitive estimation.' Thus the problems in performing cognitive estimations on temporal themes which were demonstrated very clearly in chapter 12 could also confound studies of time experience which utilise verbal estimation methods (see also

Shaw & Aggleton,1994). This may result in the production of set responses given to all tasks. For example, in chapter 10, SMH tended to given a response of "a couple of minutes" to tasks which ranged in duration from one to four minutes. Typically these kinds of deficits arise in the context of preservation of knowledge about time. Thus there are a number of potential sources of verbal response bias ascribable to an automatic stereotypical response set, poor cognitive estimation or simply verbal perseveration. As an example of strategic adjustment, after severe brain injury a person may, for instance, select one of a set of prototypical responses which permit them to 'get by' in everyday conversation. Alternatively, this may not be a goal-oriented strategy but simply a reflection of an overlearned response which is elicited indiscriminately given a particular set of cues.

The process by which this might occur is not clear, though research on event dating suggests possible mechanisms resulting from the way time is represented. In particular, Huttenlocher et al., (1988; 1990) proposed that whilst time is essentially continuously or metrically represented, events are represented at different hierarchical levels of precision based upon calendar time (hours, days, weeks etc.). Their account proposes that these inexact divisions of events in time constitute parameters which limit dating responses. If information at one level of the hierarchy (for example, days) is lost for whatever reason then dating becomes influenced boundaries at the next level of representation upwards: "if information is inexact at the relevant level of detail the boundaries arising from the division of larger units will lead to biases in the estimation" (Huttenlocher et al.,1988, pg.471). Thus subjects are hypothesised to impose a boundary on their responses based on their notion of what would constitute a reasonable time. A similar process could plausibly operate with respect to time intervals, though in association with neuropsychological deficiencies such as impaired memory or cognitive estimation the outcome is likely to be considerably distorted.

The essence of the Huttenlocher model is the importance it places on defining duration in terms of an external temporal reference rather than simply the succession of events. It

seems likely that aspects of semantic memory may provide the foundation for such reference points in the form of knowledge about time or time action relations (see chapter 11). It follows that compensatory control mechanisms such as the recruitment of more salient external cues can ameliorate distortions of time experience (as when the memory-impaired patient identifies the date by checking their wrist-watch). However, when external temporal references are ineffective and compensatory strategies are unavailable, and when all but the most gross representation of temporal information is inaccessible, then it is to be expected that the validity of attempts to explore phenomenal time experience may be questioned, as highlighted in chapter 10 with the amnesic patient SMH.

Executive functions and Psychological Time

A second important aspect of executive functioning, one which underpins the concept of psychological time as an adaptive capability, is the ability to utilise temporal information processing in functional situations. In a review of the SAS model of executive dysfunction, Shallice and Burgess (1991a) speculated that time-based problems may be more extensive than global supervisory impairments, while studies of prospective memory have also suggested that time-based tasks may be more vulnerable to disruption than event-based tasks. In a similar vein, Hockey's (1993) model of effort regulation allows for both low-level control operations to modify action timing and higher-level supervisory-induced changes in goal state which could also reduce timing accuracy by allocating more processing resources to task. Alternatively, as a result of strategic adjustment, goal priorities themselves may be changed, which could lead to a reduction in the relevance of temporal constraints (cf. Zakay,1992).

In chapter 13 it was argued that the most systematic functional manifestation of such deficiencies occurs as part of a strategy application disorder. JW, a patient with a bifrontal meningioma, was presented. In addition to her dysexecutive deficits, JW showed marked impairment in the deployment of strategies in autobiographical and prospective memory tasks in contrast to near adequate performance on standard

anterograde recall and recognition memory tests. This profile of impairment was characterised as a deficiency in the development and utilisation of temporally-appropriate retrieval contexts which are necessary to both autobiographical recall and the realisation of intentions. The importance of this level of temporal organisation was only evident in poorly structured non-routine situations. A subtle effect of this nature could contribute to a variety of time-based difficulties in regulating behaviour such as planning (Shallice,1982; Goel,1997), problem solving (Dimitrov et al.,1996), and anticipation (Freedman et al.,1987), particularly in novel situations (Karnath et al.,1991).

A discussion such as the above, on executive contributions to time experience, illustrates that many cognitive models of time are limited by their failure to acknowledge "top-down" influences on subjective experience. Psychological time is not simply driven by events but based on a variety of other moderators which include expectations about event duration, perceived relevance of time constraints and, perhaps most crucially, the ability to modify action in response to changes in the temporal domain within which a task must be completed. Similar temporal variables have been identified as mediators of behaviour in the workplace (De Keyser,1990). Of the main theories of psychological time reviewed in chapter 2, two approaches in particular are noteworthy for their potential to accommodate a degree of 'top-down' executive mediation.

Zakay (1992) drew attention to the subjective utility of time in any given task, which he termed 'temporal relevance'. In the parlance of information theory this corresponds to a weighting function assigned to time in the allocation of processing resources in a modified internal clock for execution of a multi-component task. For JW it could be argued that the temporal relevance of events was substantially reduced as she disregarded time pressures throughout the multiple errands task. However, it may be more accurate to say that knowledge of the importance of time limits is no guarantee that this will influence behaviour in the dysexecutive patient. This is an important modification to Zakay's (1992) original proposal which is necessary to account for the behaviour of brain lesioned individuals with prefrontal dysfunction.

The second theory of psychological time with applicability to the domain of executive dysfunction is the expectancy - contrast model (Boltz,1985; Jones & Boltz,1989). This model relates experienced time to anticipated duration and to the organisation of action: "...by using the event's expected ending as an internal referent...[one can]...gauge and monitor the remaining amount of activity until the event's completion...[and also]...prepare and plan ahead for the next upcoming event," (Boltz,1993). Whereas Zakay emphasised the utility ascribed to time in a task, Boltz showed that subjects' expectations influenced experienced duration. In neuropsychological terms her notion of anticipated duration is somewhat analogous to the creation of temporal markers (Shallice & Burgess,1991a; 1991b) except that in this case the markers are designed to facilitate existing task completion rather than to interrupt on-going behaviour in order to perform a different set of actions.

In the normal population these two accounts can readily be assimilated on the basis that the perceived relevance of time influences the allocation of resources to an activity and is itself based upon its anticipated duration. However, in frontal lesioned patients (and this includes most head injured cases) it is plausible that impaired cognitive estimation will yield inadequate anticipated duration, and possibly the creation of inappropriate temporal markers. Hence the expectancy-contrast account of time experience also requires some revision to take note of possible deficiencies in the derivation of anticipated duration.

From the discussion so far it can be appreciated that time experience in real life situations is likely to be derived from many more factors than simply the limiting conditions set by memory and attention deficits. Additional moderators of subjective time include: conceptual appreciation of time, the ability to construct meaning from shared temporal representations, and the degree to which time constraints have been adequately planned for, assigned priority and monitored. So far these topics have been discussed as individual problems, but from chapter 1 it was argued that psychological

time has an essential social aspect and the implications of this now need to be considered.

14.3 The social and functional context of Psychological Time

In chapter 1 it was proposed that two principal developments have contributed to the latter-day social construction of time. Firstly, the increasing accessibility and sophistication of chronometers, clocks and watches which has endowed individuals with an ability and a responsibility to regulate their time. Secondly, increasing industrialisation has led to the notion of time as not just a finite resource but one with significant economic value.

Conceptually, this entails a departure from the more individual-centred cognitive models and the adoption of a more expansive perspective such as a narrative framework (Schank & Abelson,1995) within which the social function of time is mediated by shared temporal concepts and standard means of measuring time. Thus the narrative perspective provides a means of characterising the breakdown of social communication which may accompany cognitive disorders of temporal experience after brain injury. Although detailed investigation of these aspects of psychological time lies outside the scope of the thesis, the empirical studies have raised some concerns about the limitations of a purely cognitive orientation in a clinical context to warrant consideration of an additional approach.

For example, the significance of the difficulties in telling the time revealed in chapter 11 can only be demonstrated in a social context as they undermine the shared language of temporal representation. This is one way in which social communication about action and intent can break down, because individuals may be unable to use temporal terms to regulate their behaviour towards such ends. Alternatively, social functioning may be undermined as a result of impaired reasoning about time (chapter 12) which threatens the consensus necessary for co-ordinated time-based action.

Temporally-regulated action entails the adoption of different time scales (McGrath & Kelly,1986) which may be simultaneously operative (see chapter 1). For example, it may be crucially important that a long-awaited facsimile arrives within the next few minutes and that the resulting information is incorporated into a report to be prepared by the end of the week, whereas what occurs in the intervening next few hours is less critical. The organisation of these time frames is non-linear and complex (McGrath,1988; see chapter 2) but effective functioning requires the ability to maintain several such parameters which may be salient in any given situation.

This is of particular importance for individuals demonstrating anomalous time experience. Such effects can readily be invoked in extreme situations such as environmental deprivation or drug-induced states, but also seem to occur commonly after severe brain injury. Subjective estimates suggest that temporal passage may be experienced as much quicker than expected or just wildly inaccurately. Differences of this kind in the nature of temporal experience will disrupt the shared meaning system by which people communicate memories, perceptions and intentions. Certainly communication on temporal themes amongst very severely head-injured people tends to consist of stereotypical phrases ("happened years ago," "waiting for hours," "in a minute" etc.). Further work is planned using the technique of discourse analysis to explore the relationship between thought and language in the temporal domain.

The other manner in which it may be difficult to sustain multiple time frames occurs in the context of strategy application disorder and related deficits in the temporal organisation of behaviour (chapter 13). The functional consequences of at least some dysexecutive problems appear to reduce the temporal relevance of stimuli or limit the temporal parameters within which action is regulated to a single time frame in any situation. Problem solving deficits of this kind can be characterised by an inability to sustain multiple temporal horizons, which is likely to impose significant disability upon afflicted individuals.

14.4 Conclusion

As the preceding discussion of the cognitive organisation of time experience demonstrates, there can be no single all-encompassing theory of psychological time. The fact that time experience is subject to cognitive influences does not necessarily render the concept of an internal clock redundant. Time experience cannot readily be reduced to properties of general purpose information processing systems. Clinical studies have shown that psychological factors in temporal experience are too complex for to be encompassed by a single cognitive theory or parsimonious internal clock mechanism. However, the more sophisticated timer models incorporate cognitive variables to the extent that no purpose is served by polarising the two approaches. Instead, the notion of a modified neural timing system (eg. Block & Zakay,1996) appears to be the most fruitful approach to adopt. Additional support for some form of neural timing mechanism may be obtained from results with patients showing little conscious awareness of temporal passage whose behaviour nevertheless appears to have some temporal regulatory aspect to it. The brain mechanisms which mediate this timing process are largely unclear but evidently there is considerable inter-subject variability in time estimation after brain injury. It is probable that damage to different underlying components of a cognitive timer would produce different patterns of time distortion (Nichelli,1996) but such a level of detail is presently extremely speculative.

The clinical evidence also highlights problems inherent in verbal estimation studies and other introspective methods of assessing subjective temporal experience. The results indicate that phenomenological extrapolations from experimental results are liable to distortion if associated with severe cognitive impairment due to the confounding effect of response biases. Such time estimation biases appear most likely to be operative under verbal estimation methods, and it is noteworthy that nonverbal means such as the method of production may be a more generalisable technique.

In conclusion, it should be recalled that the primary impetus for the research was a clinical motivation to explore the multi-faceted nature of time experience in severely

brain injured individuals. Given the current economic significance of time and the sophisticated means of its measurement (chapter 2) a common experience and language of time has never been more important. It follows that the consequences of disturbances of psychological time are therefore likely to have widespread implications, depending on their nature, for social functioning. The social aspect of time is based on consensus constructed from shared temporal representations and meanings. This includes both conventional codes for time such as clocks and their interpretative "grammar," and time frames or temporal horizons (the extent to which action is influenced by events some way removed from the present).

It has been demonstrated that the notion of psychological time is a multi-faceted concept to which no specific orientation or model can do justice. Temporal awareness depends crucially on the integrity of many cognitive systems, in particular upon attention and episodic memory. Yet awareness of time also requires a medium of expression for which aspects of semantic memory are essential. It seems likely that 'temporal semantics' like some other forms of knowledge are moulded by personal experience and have idiosyncratic associations to action. The contribution of general purpose information processing systems to psychological time appears to be in terms of defining the conditions under which a neural timing system or network of systems operates. Translation of temporal awareness which this system permits into a form useful for meaningful goal-oriented behaviour requires the contribution of aspects of executive functioning, in terms of problem solving and action timing. Finally, the evolution of temporal language and the highly temporally-structured nature of the world in which many brain-injured people live necessitates that the broader social implications of their cognitive disorder are also taken into account. The first step towards being able to ameliorate some of these disabilities is to recognise the diversity of processes which can contribute to a breakdown in some aspect of the parameters of personal orientation and action which is called psychological time.

Appendices

Appendix A

Sample autobiographical questions administered in chapter 8

"Athematic" Questions (context-independent personal semantics)

What colour hair did your father have?

When is your husband's birthday?

What is your favourite holiday destination?

Which of your children lives furthest away from you now?

"Thematic" Questions (requiring a temporal reference to a specific event)

How long have you been in hospital now?

How long did your husband stay when he last visited?

How long did you attend High school for?

How long ago did you last visit the dentist?

"Sub-thematic" Questions (non-temporal details of temporally-specific events)

What was the worst illness that you had as a child?

Who were you with when you met your husband for the first time?

Where did you spend last Christmas?

What did you have for breakfast this morning?

Appendix B

A list of perceptual tasks adminstered to subjects in chapter 11.

Spatial position and enumeration

Position Discrimination: 20 judgements of relative position of black dot (5 mm.) in two horizontal squares.

Number Location: 10 identifications of appropriate numeral in square (62 mm x 62mm) corresponding to dot position in square vertically underneath.

Cube Analysis: Enumeration of ten graded arrangements of black outline representations of 3-D bricks.

Right-Left Orientation: 20 instructions involving actions demonstrating orientation towards own body, a confronting body or both.

Tests of "pre-categorical" visual processing

Length match task: 30 same/different judgements about line pairs with length discrepancies ranging from 1.8cm to 0.1 cm.

Orientation match task: 30 same/different judgements of pairs of 4.5 cm. lines (parallel/ non-parallel) ranging in gradient discrepancy from 7° to 1°.

Line Orientation task: 30 matching-to-sample judgements of two differently displaced lines (line length = 2 cm.).

Testing access to stored knowledge about objects

Object Decision task: Two sets of 32 line drawings of 16 real and 16 unreal objects (animals and tools) in an EASY and a HARD version.

Object Decision Silhouettes: 20 forced-choice arrays of one real object and three distractor minimal view silhouettes.

Appendix C

Deviation scoring criteria for the shortened temporal estimates test

	Mean	1- point (+/- 2 SD)	2-point (+/- 3 SD)	3-point (+/-4 SD)
How long does it take to...				
1. Walk a mile?	15.0 min.	< 1 min.	-	-
	> 29 min.	> 37 min.	> 44 min.	-
2. Boil a kettle?	5.5 min.	> 27 min	> 37 min.	>48 min.
3. Be a brain surgeon?	8.6 yrs.	> 14 yrs.	> 16.5 yrs.	> 19 yrs.
4. Recite the months of the year?	3.5 min.	> 22 mins.	> 31 mins.	> 41 mins.
5. Dial a telephone number?	20.0 sec.	> 67 sec.	> 90 sec.	> 113 sec.
6. Read a page in a novel?	3.8 mins	> 11 mins.	> 15 mins	> 19 mins
7. Train to be a vet?	5.3 yrs.	< 21 months	< 1 month	-
	> 9 yrs.	> 11 yrs.	> 12 yrs.	-
8. A cup of coffee to go cold?	23 mins	> 83 mins.	> 114 mins	>144 mins.
9. To develop a photograph?	15.7 mins.	> 55 mins.	> 75 mins.	>95 mins.
10. To play a game of football	91.2 mins.	< 60 mins.	< 43 mins	<28 mins.
	>123 mins.	> 138 mins	>154 mins.	-
11. Watch a film at the cinema?	109.6 mins.	< 53 mins	< 25 mins	-
	> 166 mins.	> 194 mins.	>223 mins.	-
12. Travel London to Edinburgh by train?	5.2 hrs.	< 2 hrs.	< 10 mins.	-
	> 8.5 hrs.	> 10.5 hrs	> 12 hrs.	> 14 hrs

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References

Adam B. (1992) Modern Times: The technology connection and its implications for social theory. *Time and Society* **1** 175-191.

Ahmadi KS (1984) Effects of social influences and waiting on time judgment. *Perceptual and Motor Skills* **59** 771-776.

Aitken S, Chase S, McCue M, Ratcliff G (1993) An American Adaptation of the Multiple Errands Test: Assessment of Executive Abilities in Everyday Life (Abstract). *Archives of Clinical Neuropsychology* **8** 212.

Alderman N (1994) Maximising the learning potential of brain injured patients. Unpublished PhD thesis, University of Southampton.

Alderman N (1996) Central executive deficit and response to operant conditioning methods. *Neuropsychological Rehabilitation* **6** 161-186

Alexandre A, Colombo F, Nertempi P & Benedetti A (1980) Cognitive outcome and early indices of severity of head injury. *Journal of Neurosurgery* **59** 751-761.

Allan LG (1992) The internal clock revisited. In Macar F, Pouthas V & Friedman WJ (eds) *Time, Action and Cognition* Dordrecht, The Netherlands: Kluwer Academic. p.191-202.

Allport DA (1968) Phenomenal simultaneity and the perceptual moment hypothesis. *British Journal of Psychology* **59** 395-406.

Anderson SW, Damsio H, Dallas Jones R & Tranel D (1991) Wisconsin card sorting test performance as a measure of frontal lobe damage. *Journal of Clinical and Experimental Neuropsychology* **13** 909-922.

Artieda J & Pastor MA (1996) Neurophysiological mechanisms of temporal perception. In: Pastor MA & Artieda J (eds) *Time, Internal Clocks and Movement.* Amsterdam: Elsevier, p.1-25.

Artieda J, Pastor MA, Lacruz F & Obeso JA (1992) Temporal discrimination is abnormal in Parkinson's diesase. *Brain* **115** 199-210.

Atkinson RC, Herrnstein RJ, Linzey G & Luce RD (1988) (eds) *Stevens' Handbook of Experimental Psychology. Vol.1 Perception and Motivation.* New York: Wiley. 905pp.

Axelrod BN & Millis SR (1994) Preliminary standardization of the Cognitive Estimation Test. *Assessment* **1** 269-274.

Axelrod BN, Goldman RS, Heaton RK, Curtiss G, Thompson LL, Chelune GJ & Kay GG (1996) Discriminability of the Wisconsin Card Sorting Test using the standardisation sample. *Journal of Clinical and Experimental Neuropsychology* **18** 338-342.

Azouvi P, Jokic C, Van Der Linden M, Marlier N & Bussel B (1996) Working memory and supervisory control after severe closed head injury. A study of dual task performance and random generation. *Journal of Clinical and Experimental Neuropsychology* **18** 317-337.

Baddeley AD (1982) Domains of recollection. *Psychological Review* **89** 708-729.

Baddeley A & Weiskrantz L (1993) *Attention: Selection, Awareness and Control.* Oxford: Clarnedon Press, 436pp.

Baddeley AD & Wilson BA (1986) Amnesia, autobiographical memory and confabulation. In: Rubin D (ed) *Autobiographical Memory.* New York: Cambridge University Press.

Bakan P (1955) Effect of set and work speed on time estimation. *Perceptual and Motor Skills* **5** 147-148.

Barclay CR & Decooke PA (1985) Ordinary everyday memories: some of the things of which selves are made. In: Neisser U & Winograd E (eds) *Remembering Reconsidered: Ecological and traditional approaches to the study of memory,* p.91-125.

Baxter D & Warrington EK (1986) Ideational agraphia a single case study. *Journal of Neurology, Neurosurgery and Psychiatry* **49** 369-374.

Baxter LR, Saxena S, Brody AL, Ackermann RF, Colgan M, Schwartz JM, Allen-Martinez Z, Fuster JM & Phelps ME (1996) Brain mediation of obsessive-compulsive disorder symptoms: evidence from functional brain imaging studies in the human and nonhuman primate. *Seminars in Clinical Neuropsychiatry* **1** 32-47.

Benton A.L., deS Hamsher K., Varney N.R. & Spreen O. (1983) *Contributions to Neuropsychological Assessment.* New York: Oxford University Press.

Berg M (1979) Temporal duration as a function of information processing. *Perceptual and Motor Skills* **49** 988-990.

Bergmann W. (1992) The Problem of Time in Sociology: An overview of the literature on the state of theory and research on the "Sociolology of Time," 1900-82. *Time and Society* **1** 81-134.

Bergson H. (1910) *Time and Free Will*. London: Allen & Unwin, 252pp.

Bergson H. (1911) *Matter and Memory*. London: Allen & Unwin.

Berlyne DE (1966) Effects of spatial order and inter-item interval on recall of temporal order. *Psychonomic Science* **6** 375-376.

Bhattacharyya GK & Johnson RA (1977) *Statistical Concepts and Methods* New York: Wiley, 639pp.

Bindra D & Waksberg H (1956) Methods and terminology in studies of time estimation. *Psychological Bulletin* **53** 155-159.

Binofski F & Block RA (1996) Accelerated time experience after left frontal cortex lesion. *Neurocase* **2** 485-493.

Bizo LA & White GK (1995) Reinforcement context and pacemaker rate in the behavioral theory of timing. *Animal Learning and Behavior* **23** 376-382.

Block R (1974) Memory and the experience of duration in retrospect. *Memory and Cognition* **2** 153-160.

Block RA (1978) Remembered duration: Effects of event and sequence complexity. *Memory and Cognition* **6** 320-326.

Block RA (1979) Time and Consciousness. In Underwood G & Stevens R (eds) *Aspects of Consciousness vol 1. Psychological Issues*. Lodon: Academic Press. p179-217.

Block RA (1984) Contextual coding in memory: studies of remembered duration. In: Michon JA & Jackson JL (eds) *Time, Mind and Behavior*. Berlin: Springer-Verlag, p.169-178.

Block RA (1989) Experiencing and remembering time: affordances, context and cognition. In: Levin I & Zakay D (eds) *Time and Cognition: A Lifespan Perspective*. Amsterdam: North-Holland, p.333-363.

Block RA (1990a) *Cognitive Models of Psychological Time.* Hillsdale, N.J.: Lawrence Erlbaum, 283pp

Block RA (1990b) Models of psychological time. In Block RA (ed) *Cognitive Models of Psychological Time.* Hillsdale, N.J.: Lawrence Erlbaum, p.1-35.

Block RA (1992) Prospective and retrospective duration judgment: the role of information processing and memory. In: Macar F, Pouthas V & Friedman WJ (eds) *Time, Action and Cognition.* Dordrecht: Kluwer Academic, p.141-152.

Block RA (1996) Psychological time and memory systems of the brain. In: JT Fraser & MP Soulsby (eds) *Dimensions of time and life: the study of time VIII.* Madison, CT: International Universities Press, p.61-76.

Block RA & Reed MA. (1978) Remembered Duration: Evidence for a Contextual Change Hypothesis. *Journal of Experimental Psychology: Human Learning and Memory* **4** 656-665.

Block RA, George EJ, Reed MA (1980) A watched pot sometimes boils. A study of duration experience. *Acta Psychologica* **46** 81-94

Block RA & Zakay D (1996) Models of psychological time revisited. In: helfrich H (ed) *Time and Mind.* Kirkland, WA: Hogrefe & Huber, p.171-195.

Boltz M (1985) *An expectancy model of judged duration: An ecological perspective.* Unpublished doctoral dissertation, Ohio State University.

Boltz M (1993) Time estimation and expectancies. *Memory and Cognition* **21** 853-863.

Boring EG (1933/63) *The Physical Dimensions of Consciousness.* New York: Dover. 215pp.

Bowers D, Verfaellie M, Valenstein E & Heilman K (1988) Impaired acquisition of temporal information in retrospenial amnesia. *Brain and Cognition* **8** 47-66.

Bracha V, Zhao L, Wunderlich DA, Morrissy SJ & Bloedel JR (1997) Patients with cerebellar lesions cannot acquire but are able to retain conditioned eyeblink reflexes. *Brain* **120** 1401-1413.

Bradley FH (1964) The Unreality of Space and Time. In Smart JJC (ed) *Problems of Space and Time.* New York: Macmillan. p132-138.

Brazzalli M, Colombo N, Della Sala S & Spinnler H (1994) Spared and impaired cognitive abilities after bilateral frontal damage. *Cortex* **30** 27-51.

Bressler SL (1996) Large-scale integration of cortical information processing. In: Pastor MA & Artieda J (eds) *Time, Internal Clocks and Movement.* Amsterdam: Elsevier, p.53-68.

British Psychological Society (1989) *Services for young adult patients with acquired brain damage.* BPS Working Party Report, October 1989. Leicester: The British Psychological Society.

Brouwer WH, Ponds RWHM, Van Wolffelaar PC & Van Zommeren AH (1989) Divided attention 5 to 10 years after severe closed head injury. *Cortex* **25** 219-230.

Brown SW (1985) Time perception and attention: the effects of prospective and retrospective paradigms and task demands on perceived duration. *Perception and Psychophysics* **38** 115-124.

Brown SW & West AN (1990) Multiple timing and the allocation of attention. *Acta Psychologica* **75** 103-121.

Brown SW, Stubbs DA & West (1992) Attention, multiple timing and psychophysical scaling of temporal judgments. In: Macar F, Pouthas V & Friedman WJ (eds) *Time, Action and Cognition.* Dordrecht: Kluwer Academic, p.129-140.

Bruyer R & Bontemps-Devogel N (1979) Lesions du cortex et perception de la duree: approache neuro-physiologique de la "chronognosie." *Journal of Psychology, Normal and Pathological.* **79** 279-297.

Buehler R, Griffin D & Ross M (1994) Exploring the "planning fallacy": why people underestimate their task completion times. *Journal of Personality and Social Psychology* **67** 366-381.

Burgess PW (1997) Theory and methodology in executive function research. In: Rabbitt P (ed) *Methodology of Frontal and Executive Function.* Hove: Psychology Press, p.81-116.

Burgess PW & Shallice T (1996a) Response suppression, initiation and strategy use following frontal lobe lesions. *Neuropsychologia* **34** 263-273.

Burgess PW & Shallice T (1996b) Bizarre responses, rule detection and frontal lobe lesions. *Cortex* **32** 241-259.

Burgess PW & Shallice T (1996c) Confabulation and the control of recollection. Memory **4** 359-411.

Burgess PW & Shallice T (1997) The relationship between prospective and retrospective memory: neuropsychological evidence. In: M Conway (ed) *Cognitive Models of Memory*. Hove: Taylor & Francis, p.247-272.

Burnside W (1971) Judgment of short time intervals while performing mathematical tasks. P*erception and Psychophysics* **38** 115-124.

Burt CDB (1992) Reconstruction of the duration of autobiographical events. *Memory and Cognition* **20** 124-132.

Burt CDB & Kemp S (1991) Retrospective duration estimation of public events. *Memory and Cognition* **19** 252-262.

Burton E. (1979/1993) *The History of Clocks and Watches*. London: Little Brown & Co. 287pp.

Cahoon D & Edwards EM (1980) The watched pot still won't boil: Expectancy as a variable in estimating the passage of time. *Bulletin of the Psychonomic Society* **16** 115-116.

Caine D, Halliday GM, Kril JJ & Harper CG (1997) Operational criteria for the classification of chronic alcoholics: identification of Wernicke's encephalopathy. *Journal of Neurology, Neurosurgery and Psychiatry* **62** 51-60.

Campbell J. (1989) *Winston Churchill's Afternoon Nap*. London: Paladin, 432pp.

Campbell J (1994) *Past, Space and Self.* Cambridge, MA: MIT Press, 270pp.

Campbell J (1996) Human vs. animal time. In: Pastor MA & Artieda J (eds) *Time, Internal Clocks and Movement*. Amsterdam: Elsevier, p.115-126.

Campbell SS (1990) Circadian Rhythms and Human Temporal Experience. In Block RA (ed) *Cognitive Models of Psychological Time*. Hillsdale, N.J.: Lawrence Erlbaum, p.101-118.

Capek M. (ed) (1976) *The Concepts of Space and Time.* Dordrecht, Netherlands: D. Reidel Publishing Co.

Carr CE & Amagai S (1996) Processing of temporal information in the brain. In: Pastor MA & Artieda J (eds) *Time, Internal Clocks and Movement.* Amsterdam: Elsevier, p.27-52.

Carrel A (1931) Physiological time. *Science* **74** 618.

Casini L, Macar F & Grondin S (1992) Time estimation and attentional sharing. In: Macar F, Pouthas V & Friedman WJ (eds) *Time, Action and Cognition.* Dordrecht: Kluwer Academic, p.177-180.

Chamberlain MA, Neumann V & Tennant A (1995) *Traumatic Brain Injury Rehabiltation.* London: Chapman & Hall, 273pp.

Chattopadhyay PK, Biswas PK & Basu AK (1980) Time estimation in psychiatric patients and normal subjects: an experimental study. *Indian Journal of Clinical Psychology* **7** 43-46.

Chen YC, Thaler D, Nixon PD, Stern CE, Passingham RE (1995) The functions of the medial premotor cortex II. The timing and selection of learned movements. *Experimental Brain Research* **67** 241-289.

Chertkow H & Bub D (1990) Semantic memory loss in dementia of the Alzheimer's type. What do various measures mean? *Brain* **113** 397-417.

Chertkow H, Bub D & Caplan D (1992) Constraining theories of semantic memory processing: evidence from dementia. *Cognitive Neuropsychology* **9** 327-365.

Cipolotti L (1995) Multiple routes for reading words, why not numbers? Evidence from a case of arabic number dyslexia. *Cognitive Neuropsychology* **12** 313-342.

Cipolotti L, Butterworth B & Denes G. (1991) A specific deficit for numbers in a case of dense acalculia. *Brain,* **114,** 2619-2637.

Cipolotti L., Butterworth B. & Warrington E.K. (1994) From "One thousand nine hundred and forty-five" to 1000,945. *Neuropsychologia,* **32,**

Clausen J (1950) An evaluation of experimental methods of time judgment. *Journal of Experimental Psychology* **40** 756-761.

Clarke S, Ivry R, Grinband J, Roberts S & Shimizi N (1996) Exploring the domain of the cerebellar timing system. In: Pastor MA & Artieda J (eds) *Time, Internal Clocks and Movement*. Amsterdam: Elsevier, p.257-280.

Clarke S, Assal G, Bogousslavssky J, Regli F, Townsend DW, Leenders KL & Blecic S (1994) Pure amnesia after unilateral left polar thalamic infarct: topographical and sequential neuropsychological and metabolic (PET) correlations. J Neurol Neurosurg Psychiatry **57** 27-34.

Cockburn J (1995) Task interruption in prospective memory: a frontal lobe function? *Cortex* **31** 87-97.

Cockburn J (1996a) Assessment and treatment of prospective memory deficits. In: Brandimonte M, Einstein GO & McDaniel MA (eds) *Prospective Memory. Theory and Applications*. Mahwah, N.J.: Lawrence Erlbaum, p.327-350.

Cockburn J (1996b) Failure of prospective memory after acquired brain damage: preliminary investigation and suggestions for future directions. *Journal of Clinical and Experimental Neuropsychology* **18** 304-309.

Cohen J (1967) *Psychological Time in Health and Disease*. Springfield, Illinois: Carels C Thomas.103pp.

Cohen JD & Servan-Schreiber D (1992) Context, cortex and dopamine: a connectionist approach to behavior and biology in schizophrenia. *Psychological Review* **99** 45-77.

Cohen L., Dehaene S. & Verstichel P. (1994) Number words and number non-words. A case of deep dyslexia extending to arabic numerals. *Brain,* **117,** 267-279.

Cohen L. & Dehaene S. (1991) Neglect dyslexia for Numbers? A Case Report. *Cognitive Neuropsychology,* **8,** 39-58.

Cornford FM. (1950) Plato and Parmenides. London: Routledge & Kegan Paul. Pages 33-39 reprinted as "The Elimination of Time by Parmenides" in Capek M. (ed) (1976) *The Concepts of Space and Time*. Dordrecht, Netherlands: D. Reidel Publishing Co., p.137-142.

Coughlan AK & Hollows S (1985) *The Adult Memory and Information Processing Battery*. Leeds: St. James University Hospital.

Craik FIM (1983) On the transfer of information from temporaray to permanent memory. *Philosophical Transactions of the Royal Society of London* **B302** 341-359.

von Cramon DY (1992) Focal cerebral lesions damaging (subcortical) fibre projections related to memory and learning functions in man. In Vallar G, Cappa SF, Wallesch C-W (eds) *Neuropsychological Disorders Associated with Subcortical Lesions.* New York: Oxford University Press, pp 132-142.

Crawford J.R., Allan K.M. & Jack A.M. (1992) Short-forms of the UK WAIS-R: Regression equations and their predictive validity in a general population sample. *British Journal of Clinical Psychology* **31** 191-202.

Dalla Barba G, Cipolotti L & Denes G (1990) Autobiographical memory loss and confabulation in Korsakoff's syndrome: A case report. *Cortex* **23** 575-597.

Dalla Barba G (1993) Confabulation: Knowledge and Recollective Experience. *Cognitive Neuropsychology* **10** 1-20.

Dall'Ora P, Della Salla S & Spinnler (1986) Autobiographical memory. Its impairment in amnesic syndromes. *Cortex* 199-217.

Damasio AR, Eslinger PJ, Damasio H, Van Hoesen GWV & Cornell S (1985a) Multimodal amnesic syndrome following bilateral temporal and basal forebrain damage. *Archives of Neurology* **42** 252-259.

Damasio AR, Graff-Radford NR, Eslinger PJ, Damasio H & Kassell N (1985b) Amnesia following basal forebrain lesions. *Archives of Neurology* **42** 263-271.

Damasio AR, Tranel D & Damasio HC (1991) Somatic markers and the guidance of behaviour. In: Levin HS, Eisenberg HM & Benton AL (eds) *Frontal Lobe Function and Dysfunction.* New York: Oxford University Press, p.217-229.

Daum I & Ackermann H (1995) Cerebellar contributions to cognition. *Behavioral Brain Research* **67** 201-210.

Davidson GM (1941) A syndrome of time agnosia. *Journal of Nervous and Mental Disease.* **94** 336-343.

Day BL (1996) A hierachical model of motor timing. In: Pastor JA & Artieda J (eds) *Time, Internl Clocks and Movement.* Amsterdam: Elsevier, p.223-234.

Dehaene S. (1992) Varieties of numerical abilities. *Cognition,* **44,** 1-42.

De Keyser V (1990) Temporal decision making in complex environments. *Philosophical Transactions of the Royal Society of London* **B327** 569-576.

Deloche G. & Seron X. (1987) Numerical transcoding: a general production model. In Deloche G & Seron X. (Eds.) *Mathematical disabilities: A Cognitive Neuropsychological Perspective.* Hillsdale, NJ: Lawrence Erlbaum.

Della Sala S & Logie RH (1998) Impairments of methodology and theory in cognitive neuropsychology. *Neuropsychological Rehabilitation* **7** 367-385.

Densen ME (1977) Time perception and schizophrenia. *Perceptual and Motor Skills* **44** 436-438.

De Renzi E., Liotti M. & Nichelli P. (1987) Semantic amnesia with preservation of autobiographical memory: A Case Report. *Cortex* **23** 575-597.

Diamond BJ, DeLuca J & Kelley SM (1997) Memory and executive functions in amnesic and non-amnesic patients with aneurysms of the anterior communicating artery. *Brain* **120** 1015-1025.

Diamond BJ, Mayes AR & Meudell PR (1996) Autonomic and recognition indices of memory in amnesic and healthy control subjects. *Cortex* **32** 439-459.

Dimitrov M, Grafman J & Hollnagel C (1996) The effects of frontal lobe damage on everyday problem solving. *Cortex* **32** 357-366.

Dobbs AR & Reeves MB (1996) Prospective memory: more than memory? In: Brandimonte M, Einstein GO & McDaniel MA (eds) *Prospective Memory: Theory and Applications.* Mahwah, N.J.: Lawrence Erlbaum, pp.199-225.

Doob LW (1971) *Patterning of Time.* New Haven: Yale University Press, 472pp.

Doty RW (1990) Time and Memory. In McGaugh JL, Weinberger NM & Lynch G (eds) *Brain Organization and Memory: Cells, systems and Circuits* New York: Oxford University Press. p145-158.

Dowker A, Fllod A, Griffiths H, Harriss L & Hook L (1996) Estimation strategies of four groups. *Mathematical Cognition* **2** 113-135.

Dum RP & Strick PL. The congulate motor areas. In: Vogt BA & Gabriel M (eds) *Neurobiology of the Congulate Cortex and Limbic Thalamus.* Boston: Birkhauser, 415-441.

Dunne JW (1934) *An Experiment with Time.* London: Faber & Faber, 306pp.

Edelman G (1990) *The Remembered Present: A Biological Theory of Consciousness.* New York, Basic books.

Einstein GO & McDaniel MA (1996) Retrieval processes in prospective memory: theoretical approaches and some new findings. In: Brandimonte M, Einstein GO & McDaniel MA (eds) *Prospective Memory, Theory and Applications.* Mahwah, N.J.: Lawrence Erlbaum Associates, p.115-141.

Eisendrath CR (1971) *The Unifying Moment. The Psychological Philosophy of William James and Alfred North Whitehead.* Cambridge, MA: Harvard University Press. 290pp.

Eslinger PJ & Damasio AR (1985) Severe disturbance of higher cognition after bilateral frontal lobe ablation. *Neurology* **35** 1731-1741.

Eslinger PJ & Grattan LM (1993) Frontal lobe and frontal striatal substrates for different forms of human cognitive flexibility. *Neuropsychologia* **31** 17-28.

Estes WK (1984) Memory for temporal information. In: Michon JA & Jackson JL (eds) *Time, Mind and Behavior.* Berlin: Springer-Verlag, p.151-168.

Everitt BS (1996) *Making Sense of Statistics in Psychology.* New York: Oxford University Press, 350pp.

Evyatar A, Stern MJ, Schem-Tov M. & Groswasser Z. (1990) Hypothesis Forming and Computerized Cognitive Therapy. In R.L.Wood & Fussey I. (eds.) *Cognitive Rehabilitation in Perspective.* London: Taylor and Francis.

Eysenck MW & Keane MT (1990) *Cognitive Psychology.* Hove: Lawrence Erlbaum.

Farah MJ (1990) Visual Agnosia. Cambridge, MA.: MIT Press, 190pp.

Fentress J & Wickham C (1992) *Social Memory.* Oxford: Blackwell, 229pp.

Ferguson RP & Martin P (1983) Long-term temporal estimation in humans. *Perception and Psychophysics* **33** 585-592.

Fleury M, Macar F, Bard C, Teasdale N, Paillard J, Lamarre Y & Forget R. (1994) Production of short timing responses: a comparative study with a deafferented patient. *Neuropsychologia* **32** 1435-1440.

Forrester G, Encel J & Geffen G (1994) Measuring post-traumatic amnesia (PTA): an historical review. *Brain Injury* **8** 175-184.

Fortin C, Rousseau R, Bourque P & Kirouac E. (1993) Time estimation and concurrent nontemporal processing: Specific interference from short-term-memory demands. *Perception and Psychophysics* **53** 536-548.

Foster JK, Eskes GA & Stuss DT (1994) The Cognitive neuropsychology of attention: A frontal lobe perspective. *Cognitive Neuropsychology* **11** 133-147.

Fraisse P (1963) *The Psychology of Time.* (trans. J. Leith). New York: Harper Row, 343pp.

Fraisse P (1973) Temporal isolation, activity rhythms and time isolation. In *Man in Isolation and Confinement.* Rasmussen JL (ed) Chicago: Aldine. p.85-98.

Fraisse P (1979) Influence de la duree du traitement de l'information sur l'estimation du'une duree d'une seconde. Annee Psychologie **79** 495-504.

Fraisse P (1984) Perception and Estimation of Time. *Annual Review of Psychology* **35** 1-36.

Francois M (1928) Contribution a l'etude du sens du temps. *Annee Psychologie* **28** 186.

Frankenhauser M. (1959) *Estimation of time: An experimental study.* Stockholm: Almquist & Wiksell.

Freeman M (1993) *Rewriting the self: history, memory and narrative.* London: Routledge, 249pp.

Freedman PE, Bleiberg J & Freedland K (1987) Anticipatory behaviour deficits in closed head injury. *Journal of Neurology, Neurosurgery and Psychiatry* **50** 398-401.

Freyd JJ (1992) Dynamic representations guiding behaviour. In: Macar F, Pouthas V & Friedman WJ (eds) *Time, Action and Cognition.* Dordrecht: Kluwer Academic, p.309-324.

Friedman WJ. (1982) Conventional time Concepts and children's Structuring of Time. In Friedman WJ. (ed) *The Developmental Psychology of Time.* NewYork: Academic Press.

Friedman WJ. (1990) *About Time.* Cambridge, MA: MIT Press, 147pp.

Fuster JM (985) The prefrontal cortex, mediator of cross-temporal contingencies. *Human Neurobiology* **4** 169-179

Gale RM. (1968) *The Language of Time.* New York: Routledge & Kegan Paul, 248pp.

Gallassi R, Lorusso S & Stracciari A (1986) Neuropsychological findings during a transient global amnesia attack and its follow-up. *Italian Journal of Neurological Sciences* **7** 45-49.

Gergen KJ (1971) *The Concept of Self.* New York: Holt, Reinhart & Winston, 110pp.

Gibson JJ (1975) Events are Perceivable But Time is Not. In: Fraser JT & Lawrence N (eds) *The Study of Time, vol.II.* Berlin: Springer-Verlag. p295-301.

Glicksohn J, Mourad B & Pavell E (1992) Imagination, Absorption and Subjective Time Estimation. *Imagination, Cognition and Personality* **11** 167-176.

Glisky EL (1996) Prospective memory and the frontal lobes. In: Brandimonte M, Einstein GO & McDaniel MA (eds) *Prospective Memory, Theory and Applications.* Mahwah, N.J.: Lawrence Erlbaum Associates, p.249-266.

Godefroy O, Duhamel A, Leclerc X, Saint Michel T, Henon H & Leys D (1998) Brain-behaviour relationships. Some models and related statistical procedures for the study of brain damaged patients. *Brain* **121** 1545-1556.

Goel V, Grafman J, Tajik J, Gana S & Danto D (1997) A study of the performance of patients with frontal lobe lesions in a financial planning task. *Brain* **120** 1805-1822.

Goldstein LH, Bernard S, Fenwick PBC, Burgess PW & McNeil J (1993) Unilateral frontal lobectomy can produce strategy application disorder. *Journal of Neurology Neurosurgery and Psychiatry* **56** 274-276.

Gonzales A & Zimbardo PG. (1985) Time in Perspective. *Psychology Today* **19** 21-26.

Gorman BS & Wessman AE (1977) Images, values and concepts of time in psychological research. In Gorman BS & Wessman AE (eds) *The Personal Experience of Time.* New York: Plenum Press.

Grafman J, Sirigu A, Spector L, Hendler J (1993) Damage to the prefrontal cortex leads to decomposition of structured event complexes. *Journal of Head Trauma Rehabilitation* **8** 73-87.

Grafman J, litvan I, Gomez C & Chase T (1990) Frontal lobe function in Progressive Supranuclear Palsy. *Archives of Neurology* **47** 553-558.

Graham KS, Becker JT, Patterson K & Hodges JR (1997) Lost for words: a case of primary progressive aphasia? In: Parkin AJ (Ed) *Case Studies in the neuropsychology of Memory.* Hove: Psychology Press, p.83-110.

Gron G (1996) Cognitive slowing in patients with acquired brain damage: an experimental approach. *Journal of Clinical and Experimental Neuropsychology* **18** 406-415.

Grondin S & Macar F (1992) Dividing attention between temporal and nontemporal tasks: a performance operating characteristic -POC- analysis. In: Macar F, Pouthas V & Friedman WJ (eds) *Time, Action and Cognition.* Dordrecht, The Netherlands: Kluwer Academic, p.119-128.

Grossi D., Modafferi, A., Delosi, L. & Trojano, L. (1989) On the different roles of the cerebral hemispheres in mental imagery: The "O'Clock Test" in two clinical cases. *Brain and Cognition,* **10,** 18-27.

Grskovic JA, Zentall SS & Stormont-Spurgin M (1995) Time estimation and planning abilities: students with and without mild disabilities. *Behavioral Disorders* **20** 197-203.

Grunebaum A (1963) *Philosophical Problems of Space and Time.* New York: A.A.Knopf, 448pp.

Grunebaum A (1964) Time, irreversible processes, and the physical status of becoming. In Smart JJC (ed) *The Problems of Space and Time.* New York: Macmillan, p.397-425.

Grunebaum A. (1968) The Status of Temporal Becoming, in Gale R. (ed) *The Philosophy of Time.* London: Macmillan, p.322-354.

Grunebaum A (1971) The Status of Temporal Becoming, in Zeman J (ed) *Time in Science and Philosophy* Prague: Elsevier, p.67-87.

Hancock PA (1993) Body temperature influence on time perception. *Journal of General Psychology* **120** 197-216.

Hanley JR, Davies ADM, Downes JJ & Mayes AR (1994) Impaired Recall of Verbal Material Following Rupture and Repair of an Anterior Communicating Artery Aneurysm. *Cognitive Neuropsychology* **11** 543-578.

Harris JE (1984) Remembering to do things. In JE Harris & PE Morris (eds) *Everyday Memory: Actions and Absent-Mindedness.* London: Academic Press.

Hartson JJ (1942) Time estimation in relation to goal-organization and difficulty of tasks. *The Journal of General Psychology* **27** 63-69.

Hasher L & Zacks RT (1979) Automatic and effortful processes inmemory. *Journal of Experimental Psychology: General* **108** 356-388.

Hawkins MF, Telford WH (1976) Effects of interest and relatedness on estimated duration of verbal material. *Bulletin of the Psychomonic Society* **8** 301-302.

Heidegger M. (1962) *Being and Time.* (Trans. Macquarrie J & Robinson E) London: SCM Press. 589pp.

Heuer H & Schmidt RA (1988) Transfer of Learning among motor patterns with different relative timing. *Journal of Experimental Psychology: Human Perception and Performance* **14** 241-252.

Hicks RE (1992) Prospective and retrospective judgments of time: a neurobehavioral analysis. In Macar F, Pouthas V & Friedman WJ (eds) *Time, Action and Cognition.* Dordrecht: Kluwer Academic, p.97-108.

Hicks RE, Miller GW & Kinsbourne M (1976) Prospective and retrospective judgments of time as a function of amount of nformation processed. *American Journal of Psychology* **89** 719-730.

Hoagland H (1936) Pacemakers of human brainwaves in normals and in general paretics. *American Journal of Physiology* **116** 604.

Hoagland H (1966) Some biochemical considerations of time. In Fraser JT (ed) *The Voices of Time.* New York: George Braziller, p.312-329.

Hochhaus L, Swanson LG & Carter AL (1991) Common words are longer in apparent duration than are rare words. *Journal of General Psychology* **118** 83-95.

Hockey GRJ (1990) Cognitive-energetical control mechanisms in the management of work demands and psychological health. In: Baddeley AD & Weiskrantz L (eds) *Attention: Selection, Awareness and Control.* Oxford: Clarendon Press.

Hockley WE & Cristi C (1996) Tests of encoding trade-offs between item and associative information. *Memory and Cognition* **24** 202-216.

Hodges JR (1991) *Transient Amnesia. Clinical and neuropsychological aspects.* London: WB Saunders.

Hodges JR & McCarthy RA (1993) Autobiographical amnesia resulting from bilateral paramedian thalamic infarction. A case study in cognitive neurobiology. *Brain* **116** 921-940.

Hodges JR & McCarthy RA (1995) Loss of remote memory: a cognitive neuropsychological perspective. *Curent Opinion in Neurobiology* **5** 178-183.

Hodges, J.R., Patterson, K., Oxbury, S. & Funnell, E. (1992) Semantic Dementia. Progressive fluent aphasia with temporal lobe atrophy. *Brain,* **115,** 1783-1806.

Hodges JR, Patterson K, Tyler LK (1994) Loss of Semantic Memory: Implications for the Modularity of Mind. *Cognitive Neuropsychology* **11** 505-542.

Hogan HW (1978) A theoretical reconciliation of competing views of time perception. *American Journal of Psychology* **91** 417-428.

Holubar J (1969) *The Sense of Time.* Cambridge, MA: MIT Press. 122pp.

Hornik J (1992) Time estimation and orientation mediated by transient mood. *Journal of Socio-economics* **21** 209-227.

Hunkin NM & Parkin AJ (1993) Recency judgments in Wernicke-Korsakoff and post-encephalitic amnesia: influences of proactive interference and retention interval. *Cortex* **29** 485-499.

Hunkin NM, Parkin AJ & Longmore BE (1994) Aetiological variation in the amnesic syndrome: comparisons using the list discrimination task. *Neuropsychologia* **32** 819-825.

Hunt RR & Smith RE (1996) Accessing the particular from the general: The power of distinciveness in the context of organisation. *Memory and Cognition* **24** 217-225.

Hurst W & Volpe BT (1982) Temporal order judgments with amnesia. *Brain and Cognition* **1** 294-306.

Huttenlocher J, Hedges L & Prohaska V (1988) Hierarchical organization in ordered domains: estimating the dates of events. *Psychological Review* **95** 471-484.

Huttenlocher J, Hedges LV & Bradburn NM (1990) Reports of elapsed time: bounding and rounding processes in estimation. *Journal of Experimental Psychology: Learning, Memory and Cognition* **16** 196-213.

Hymas N, Lees A, Bolton D, Epps K & Head D. (1991) The neurology of obsessional slowness. *Brain* **114** 2203-2233.

Incisa della Rocchetta AID, Milner B (1993) Strategic search and retrieval inhibition: The role of the frontal lobes. *Neuropsychologia* **31** 503-524.

Irle E, Wowra B, Kunert HJ, Hampl J, Kunze S. Memory disturbance following anterior communicating artery rupture. *Annals of Neurology* **31** 473-480.

Ishiai S., Sugishita M., Ichikawa T., Gono S. & Watabiki S. (1993) Clock-Drawing Test and Unilateral Spatial Neglect. *Neurology.* **43,** 106-110.

Ivry RB & Keele SW. (1989) Timing functions of the cerebellum. *Journal of Cognitive Neuroscience* **1** 136-152.

Ivry RB & Hazeltine RE (1995) Perception and production of temporal intervals across a range of durations: evidence for a common timing mechanism. *Journal of Experimental Psychology: Human Perception and Performance* **21** 3-18.

Ivry RB & Hazeltine RE (1992) Models of timing-with-a-timer. In: Macar F, Pouthas V & Friedman WJ (eds) *Time, Action and Cognition* Dordrecht, The Netherlands: Kluwer Academic. p.183-189.

Jackson JL (1984) Is the processing of temporal information automatic or controlled? In: Michon JA & Jackson JL (eds) *Time, Mind and Behavior.* Berlibn: Springer-Verlag, p.179-190.

Jackson JL (1990) A cognitive approach to temporal information processing. In: Block RA (ed) *Cognitive Models of Psychological Time.* Hillsdale, NJ: Lawrence Erlbaum, p.153-180.

Jackson JL & Michon JA (1992) Versimilar and metaphorical representations of time. In: Maccar F, Pouthas V,& Friedman WJ (eds) *Time, Action and Cognition.* Dordrecht: Kluwer Academic. 349-360.

Jackson M. & Warrington E.K. (1986) Arithmetical skills in patients with unilateral cerebral lesions. *Cortex.* **22,** 611-620.

James W (1890) *The Principles of Psychology.* New York: Henry Holt.

Janet P (1928) *L'evolution de la memoire et de la notion du temps.* Paris.

Jaques E. (1982) *The Form of Time.* London: Heinemann.

Jennett B (1976) Assessment of the severity of head injury. *Journal of Neurology, Neurosurgery and Psychiatry* **39** 647-655.

Jennett B (1979) Defining brain damage after head injury. *Journal of the Royal College of Physicians of London* **13** 197-200.

Jennett B & Teasdale G (1981) *Management of Head Injuries.* Philadelphia, PA: Davis.

Jones MR & Boltz M (1989) Dynamic attending and responses to time. *Psychological Review* **96** 459-491.

Jones MR, Boltz MG, Klien JM (1993) Expected endings and judged duration. *Memory and Cognition.* **21** 646-665.

Joslyn D & Hutzell RR (1979) Temporal disorientation in schizophrenic and brain-damaged patients. *American Journal of Psychiatry* **136** 1220-1222.

Kantowitz BH (1974) Human Information orocessing: Tutorials in Performance and Cognition. Hillsdale, N.J.: Lawrence Erlbaum.

Kapur N., Ellison D., Smith M.P., McLellan D.L. & Burrows E.H. (1992) Focal Retrograde Amnesia following Bilateral Temporal Lobe Pathology. *Brain* **115** 73-85.

Kapur N (1993) Focal retrograde amnesia in neurological disease: a critical review. *Cortex* **29** 217-234.

Kapur N (1994) *Memory Disorders in Clinical Practice.* Hove: Lawrence Erlbaum, 289pp.

Kapur N (1997) Autobiographical amnesia and temporal lobe pathology. In Parkin AJ (Ed) *Case Studies in the Neuropsychology of Memory.* Hove: Psychology Press, p.37-62.

Karnath HO, Wallesch CW & Zimmerman P (1991) Mental planning and anticipatory processes with acute and chronic frontal lobe lesions: a comparison of maze performance in routine and non-routine situations. *Neuropsychologia* **29** 271-290.

Kartsounis L. & Crewes H. (1994) Horologagnosia: an impairment of the ability to tell the time. *Journal of Neurology, Neurosurgery and Psychiatry.* **57,** 384-385.

Kartsounis LD, Poynton A, Bridges PK & Bartlett JR (1991) Neuropsychological correlates of stereotactic subcaudate tractotomy *Brain* **114** 117-137.

Keele SW & Ivry R (1991) Does the cerebellum provide a common computation for diverse tasks? In: A Diamon (ed) The development and neural bases of higher cognitive function. New York: *New York Academy of Sciences* **608** 179-211.

Kemp S (1988) Dating recent and historical events. *Applied Cognitive Psychology* **2** 181-188.

Kesner RP, Hopkins RO & Fineman B (1994) Item and order dissociation in humans with prefrontal cortex damage. *Neuropsychologia* **32** 881-891.

King NS, Crawford S, Wenden FJ, Moss NEG, Wade DT & Caldwell FE (1997) Measurement of post-traumatic amnesia: how reliable is it? *Journal of Neurology, Neurosurgery and Psychiatry* **62** 38-42.

Kinsbourne M & Hicks RE (1990) The extended present: evidence from time estimation by amnesics and normals. In Vallar G (ed) *Neuropsychological Impairments of Short-term Memory.* New York: Cambridge University Press.

Kintsch W & van Dijk TA (1978) Toward a model of text comprehension and reproduction. *Psychological Review* **85** 363-394.

Kitamura T & Kumar R (1983) Time estimation and time production in depressive patients. *Acta Psychiatrica Scandanavia* **68** 15-21.

Knight RT (1984) Decreased response to novel stimuli after prefrontal lesions in man. *Electroencephalography and Clinical Neurophysiology* **59** 9-20.

Kopelman M. (1991) Frontal dysfunction and memory deficits in the alcoholic Korsakoff syndrome and Alzheimer-type dementia. *Brain* **114** 117-137.

Kopelman MD, Stanhope N & Kingsley D (1997) Temporal and spatial context memory in patients with frontal, temporal lobe and diencephalic lesions. *Neuropsychologia* **35** 1533-1545.

Kopelman MD, Wilson BA & Baddeley AD (1989) The Autobiographical Memory Interview: A new assessment of autobiographical and personal semantic memory in amnesic patients. *Journal of Clinical and Experimental Neuropsychology* **11** 724-744.

Kopelman MD, Wilson BA & Baddeley AD (1990) *The Autobiographical Memory Interview*. Bury St Edmunds: Thames Valley Test Company.

Kowal KH (1976) Apparent duration of long meaningful events and meaningless intervals. M*emory and Cognition* **4** 215-220.

Kraemer HC & Thiemann S (1987) How Many Subjects? statistical power analysis in research. Newbury Park, CA: Sage, 119pp.

Kraus JF (1978) Epidemiologic features of head and spinal cord injury. *Advances in Neurology* **53** Supp. 3-10.

Kummel F. (1966) Time as Succession and the Problem of Duration. In Fraser JT. (ed) *The Voices of Time.* New York: George Braziller.

Larue J, Bard C, Fleury M, Teasdale N, Paillard J, Forget R & Lamarre Y. (1993) Is proprioception important in the timing of motor activities? *Quebec Symposium "Deafferentiation and the role of sensory afferent in human motor control" Abstracts,* p44.

Lashley K (1929) *Brain Mechanisms and Intelligence.* Chicago: University of Chicago Press.

Leng NRC & Parkin AJ (1988) Double dissociation of frontal dysfunction in organic amnesia. *British Journal of Clinical Psychology* **27** 359-362.

Levine R & Wolf E (1985) Social time: The heartbeat of culture. *Psychology Today.* **19** 29-35.

Lewis A (1932) The experience of time in mental disorder. *Proceedings of the Royal Society of Medicine.* **25** 611-620.

Liu Y & Wickens CD (1994) Mental workload and cognitive task automaticity: an evaluation of subjective estimation metrics. *Ergonomics* **37** 1843-1854.

Luce RD & Krumhansl CL (1988) Measurement, scaling and psychophysics. In: Atkinson RC, Herrnstein RJ, Linzey G & Luce RD (eds) *Stevens' Handbook of Experimental Psychology*, New York: Wiley, p.3-74.

Luria AR (1966) *Higher Cortical Functions in Man*, London: Tavistock.

Macar F (1996) Temporal judgments on intervals containing stimuli of varying quantity, complexity and periodicity. *Acta Psychologica* **92** 297-308.

Macar F, Pouthas V & Friedman WJ (1992) *Time, Action and Cognition.* Dordrecht: Kluwer Academic, 397pp.

Macaruso P, McCloskey M. & Aliminosa D. (1993) The Functional Architecture of the Numerical-processing System: Evidence from a Patient with Multiple Deficits. *Cognitive Neuropsychology*, **10**, 341-376.

MacKay DG (1982) The problems of flexibility, fluency and speed-accuracy trade-off in skilled behaviour. *Psychological Review* **89** 483-506.

Macleod RB & Roff MF (1936) An experiment in temporal disorientation. *Acta Psychologica* **1** 381-423.

Malloy P (1987) Frontal lobe dysfunction in obsessive-compulsive disorder. In: Perecman E (ed) *The Frontal Lobes Revisited.* New York: IRBN Press, p.207-223.

Mandler G (1980) Recognizing: The judgment of previous occurrence. *Psychological Review* **87** 252-271

Manly T & Robertson IH (1997) Sustained attention and the frontal lobes. In P. Rabbitt (ed) *Methodology of frontal and executive function.* Hove: Psychology Press, p.135-153.

Marenco S, Coppola R, Daniel DG, Zigun JR, Weinberger DR. Regional cerebral blood flow during the Wisconsin Card Sorting Test in normal subjects studied by xenon-133 dynamic SPECT: comparison of absolute values, percent distribution values, and covariance analysis. Psychiat Res 1993; 50: 177-192.

Markowitsch H.J., Calabrese P., Leiss J., Haupts M., Durwen H.F. & Gehlen W. (1993) Retrograde amnesia after traumatic injury of the fronto-temporal cortex. *Journal of Neurology, Neurosurgery and Psychiatry* **56** 988-992.

Martinez MBB (1992) Testing models of time estimation. In Macar F, Pouthas V & Friedman WJ (eds) *Time, Action and Cognition.* Dordrecht: Kluwer Academic, p173-176.

Martinez MBB (1994) The role of cognitive changes in immediate and remote prospective time estimations. *Acta Psychologica* **85** 99-121.

Mattison AJ & Levin HS (1990) Frontal lobe dysfunction following closed head injury. *Journal of Nervous and Mental Disease* **178** 282-291.

Mayes A, Meudell PR & Pickering A (1985) Is organic amnesia caused by a selective deficit in remembering contextual information? *Cortex* **21** 167-202.

Mayes AR, MacDonald C, Donlan L, Pears J & Meudell PR (1992) Amnesics have a disproportionately severe memory deficit for interactive context. *Quarterly Journal of Experimental Psychology* **45A** 265-297.

Maylor EA (1995) Prospective memory in normal ageing and dementia. *Neurocase* **1** 285-289.

Mayo B. (1950) Is there a sense of duration? *Mind* **59** 71-78.

McAndrews MP & Milner B (1991) The frontal cortex and memory for temporal order. *Neuropsychologia* **29** 849-859.

McCarthy R.A. & Warrington E.K. (1992) Actors but not Scripts: The Dissociation of People and Events in Retrograde Amnesia. *Neuropsychologia* **30** 633-644.

McClain L (1983) Interval estimation: effects of processing demands on prospective and retrospective reports. *Perception and Psychophysics* **34** 185-189.

McCloskey M. & Aliminosa D. (1991) Facts, Rules and Procedures in Normal Calculation. Evidence from Multiple Single-Patient Studies of Impaired Arithmetic Fact Retrieval. *Brain and Cognition,* **17,** 154-203.

McCloskey M. & Caramazza A. (1987) Cognitive mechanisms in normal and impaired number processing. In Deloche G. & Seron X. (Eds.) *Mathematical disabilities: A Cognitive Neuropsychological Perspective.* Hillsdale, NJ: Lawrence Erlbaum.

McCloskey M., Aliminosa D. & Macaruso P. (1991) Theory-Based Assessment of Acquired Dyscalculia. *Brain and Cognition.* **17,** 285-308.

McGrath JE (1988) *The Social Psychology of Time.* Newbury Park, CA: Sage, 271pp.

McGrath JE & Kelly JR, (1992) Temporal Context and Temporal Patterning: Toward a time-centred perspective for social psychology. *Time and Society* **1** 399-420.

McGrath JE & Kelly JR (1986) Time and Human Interaction. New York: Guilford Press, 183pp.

McKenna P. & Warrington E.K. (1980) Testing for nominal dysphasia. *Journal of Neurology, Neurosurgery and Psychiatry* **43** 781-788.

McMillan TM & Glucksman EE (1987) The neuropsychology of moderate head injury. *Journal of Neurology, Neurosurgery and Psychiatry* **50** 393-397.

McMillan TM, Jongen ELMM & Greenwood RJ (1996) Assessment of post-traumatic amnesia after severe closed head injury: retrospective or prospective? *Journal of Neurology, Neurosurgery and Psychiatry* **60** 422-427.

McTaggart J.McT.E (1927) *The Nature of Existence vol.2.* (ed. C.D. Broad) Cambridge: Cambridge University Press.478pp.

Meacham JA. (1982) A note on remembering to execute planned actions. *Journal of Applied Developmental Psychology* **3** 121-133.

Meck WH (1984) Attentional bias between modalities: Effect on the clock ,memory and decision stages used in animal time discrimination. In Gibbon J & Allan LG (eds) *Timing and Time Perception. Annals of the New York Academy of Sciencies* 423. New York: New York Academy of Sciences. p.528-541.

Meck WH. (1986) Affinity for the dopamine D2 receptor predicts neuroleptic potency in decreasing the speed of an internal clock. Pharmacology, Biochemistry and Behaviour. **25** 1185-1189.

Meck WH (1988) Hippocampal function is required for feedback control of an internal clock's criterion. *Behavioral Neuroscience* **102** 54-60.

Meck WH, Church RM & Olton DS (1984a) Hippocampus, time and memory. *Behavioral Neuroscience* **98** 3-22.

Meck WH, Komeily-Zadeh FN & Church RM (1984b) Two-step Aquisition: Modification of an Internal Clock's Criterion. Journal of *Experimental Psychology: Animal Behavior Processes.* **10** 297-306.

Meck WH & Church RM (1987) Cholinergic modulation of the content of temporal memory. *Behavioural Neuroscience* **101** 457-464.

Mellor DH. (1993) The Unreality of Tense. In Le Poidevin R. & MacBeath M. (1993) *The Philosophy of Time.* Oxford: Oxford University Press, p.47-59.

Mellor DH. (1981) *Real Time.* 203pp. Cambridge: Cambridge University Press.

Mering TA (1989) Influence of destruction of the septum pellucidum on time interval estimation. *Neuroscience and Behavioral Physiology* **19** 287-293.

Meyers CA & Levin HS (1992) Temporal perception following closed head injury. *Neuropychiatry, Neuropsychology and Behavioural Neurology.* **5** 28-32.

Meyerson E. (1930) Identity and Reality. Trans. K. Loewenberg. London: Allen & Unwin. Pages 216-219,222-224, 226-231 reprinted as "The Elimination of Time in Classical Science" in Capek M. (ed) (1976) *The Concepts of Space and Time.* Dordrecht, Netherlands: D. Reidel Publishing Co., p. 255-264.

Miall RC (1992) Oscillators, predictions and time. In Macar F, Pouthas V & Friedman WJ (eds) *Time, Action and Cognition.* Dordrecht: Kluwer Academic, p.215-238.

Miall C (1996) Models of neural timing. In: Pastor MA & Artieda J (eds) *Time, Internal Clocks and Movement.* Amsterdam: Elsevier, p.69-94.

Michon JA (1967) *Time in Temporal Tracking.* Institute for Perception. Soesterberg, The Netherlands.

Michon JA (1971) Time in Psychology. In Zeman J (ed) *Time in Science and Philosophy* Prague: Elsevier. p.153-164.

Michon JA (1978) The Making of the Present: A Tutorial Review. In Requin J (ed) *Attention and Performance VII.* Hillsdale, N.J.: Lawrence Erlbaum. p. 90-111.

Michon JA & Jackson JL (1984) Attentional Effort and Cognitive Strategies in the Processing of Temporal Information. In: Gibbon J & Allan L (eds) *Timing and Time Perception.* New York: The New York Academy of Sciences, p.298-321.

Milikowski M. & Elshout J.J. (1994) Differences in the semantic integration of tabled and non-tabled numbers. *British Journal of Psychology* **85,** 25-39.

Millis SR & Dijkers M (1993) Use of the recognition memory test in traumatic brain injury: preliminary findings. *Brain Injury* **7** 53-58.

Milner B (1963) Effects of different brain lesions on card sorting. *Archives of Neurology.* **9** 90-100.

Milner B (1964) Some effects of frontal lobectomy in Man. In: Warren JM & Akert G (eds) *The Frontal Granular Cortex and Behavior.* New York: McGraw-Hill, p.313-334.

Milner B (1971) Interhemispheric differences in the localization of psychological processes in Man. *British Medical Bulletin* **27** 272-277.

Milner B, Corkin S & Teuber HL (1968) Further analysis of the hippocampal amnesic syndrome: a 14-year follow-up study of HM. *Neuropsychologia* **6** 215-234.

Milner B, Petrides M & Smith ML (1985) Frontal lobes and the temporal organisation of memory. *Human Neurobiology* **4** 137-142.

Milner B, Corsi P & Leonard G (1991) Frontal-lobe contribution to recency judgments. *Neuropsychologia* **29** 601-618.

Mishkin M (1964) Preservation of central sets after frontal lesions in monkeys. In Warren JM & Akert K (eds) *The frontal granular cortex and behavior.* New York: McGraw-Hill.

Mockler D, Riordan J & Sharma T (1996) A comparison of the NART (restandardised) with the NART-R (revised). *British Journal of Clinical Psychology* **35** 567-572.

Morris M. (1934) *Liebniz Metaphysical Writings.* London: JM Dent & Sons Ltd.

Morris MK, Bowers D, Chatterjee A, Heilman, KM (1992). Amnesia following a discrete forebrain lesion. *Brain* **115** 1827-1847.

Morris RG, Miotto EC, Feigenbaum JD, Bullock & Polkey CE (1997) The effect of goal-subgoal conflict on planning ability after frontal-and temporal-lobe lesions in humans. *Neuropsychologia* **35** 1147-1157.

Moscovitch M (1989) Confabulation and the frontal systems: strategic versus associative retrieval in neuropsychological therories of memory. In Roediger HL & Craik FIM (eds) *Varieties of Memory and Consciousness.* Hillsdale, N.J.: Lawrence Erlbaum, p.133-160

Mulligan RM & Schiffman HR (1979) Temporal experience as a function of organization in memory. *Bulletin of the Psychonomic Society* **14** 417-420.

Munzel K, Gendner G, Steinberg R & Raith L (1988) Time estimation of depressive patients: the influence of interval content. *European Archives of Psychiatry and Neurological Sciences* **237** 171-178.

Murdock BB (1974) *Human Memory: Theory and Data.* Hillsdale, N.J.: Lawrence Erlbaum.

Myers CS (1911) *A Textbook of Experimental Psychology, 2nd edition.* Cambridge: Cambridge University Press. 344pp.

Nagahama Y, Fukuyama H, Yamauchi H, Matsuzaki S, Konishi J, Shibasaki H & Kimura J (1996) Cerebral activation during performance of a card sorting test. *Brain* **119** 1667-1675.

Nakamura H. (1966) Time in Indian and Japanese Thought. In Fraser JT (ed) *The Voices of Time.* New York: George Braziller. p.77-91.

Natsoulas T (1992) The Stream of Consciousness: II William James' specious present. *Imagination, Cognition and Personality.* **12** 367-385.

Nauta WJH (1971) The Problem of the Frontal lobe: A Reinterpretation. *Journal of Psychiatric Research* **8** 167-187.

Needham J. (1966) Time and Knowledge in China and the West. In Fraser JT (ed) *The Voices of Time.* New York: George Braziller. p.92-135.

Neisser U (1967) *Cognitive Psychology* New York: Appleton-Century-Crofts. 351pp.

Nelson H (1976) A modified card sorting task sensitive to frontal lobe defects. *Neuropsychologia* **12** 313-324.

Nelson H.E. & Willison J. (1991) *National Adult Reading Test (NART) 2nd. edition.* Windsor NFER: Nelson.

Neustadter R. (1992) Beat the Clock: The mid-twentieth century protest against the reification of time. *Time and Society* **1** 379-398.

Newell A & Simon H (1972) Human problem solving. Englewood Cliffs, N.J.: Prentice-Hall.

Newton-Smith WH. (1980) *The Structure of Time.* London: Routledge & Kegan Paul. 262pp.

Nichelli P. (1996) Time perception measurements in neuropsychology. In: MA Patsor & Artieda J (eds) *Time, Internal Clocks and Movement.* Amsterdam: North-Holland, p.187-204.

Nichelli P, Venneri A, Molinari M, Tavani F & Grafman J (1993) Precision and accuracy of subjective time estimation in different memory disorders. *Cognitive Brain Research* **1** 87-93.

Noel M-P. & Seron X. (1993) Arabic Number Reading Deficit: A Single Case Study. *Cognitive Neuropsychology,* **10,** 317-339.

Norman DA & Bobrow DG (1979) Descriptions: an intermediate stage in memory retrieval. *Cognitive Psychology* **11** 107-123.

Norman DA & Rumelhart DE (1975) *Explorations in Cognition.* San Francisco; WH Freeman. 430pp.

Norman K & Schacter DL (1996) Implicit memory, explicit memory and false recognition: a cognitive neuroscience perspective. In Reder LM (ed) *Implicit Memory and Metacognition.* Hillsdale, N.J.: Lawrence Erlbaum.

Norman D & Shallice T (1986) Attention to action: willed and automatic control of behaviour. Reprinted in revised form in: Davidson RJ, Schwartz GE & Shapiro D (eds) *Consciousness and Self-Regulation, vol.4.* New York: Plenum Press.

Nowotny H. (1992) Time and Social Theory: Towards a social theory of time. *Time and Society* **1** 421-454.

O'Carroll R, Egan V & MacKenzie DM (1994) Assessing cognitive estimation. *British Journal of Clinical Psychology* **33** 193-197.

Oder W, Podreka I, Spatt J & Goldberg G (1996) Cerebral function following catastrophic brain injury: relevance of single photon emission computed tomography and positron emission tomography. In: Levin HS, Benton AL, Muizelaar JP & Eisenberg HM (eds) *Catastrophic Brain Injury.* New York: Oxford University Press, p.51-76.

Oldfield & Wingfield (1965) Response Latencies in Naming Objects. *Quarterly Journal Of Experimental Psychology.* **17** 234-244.

Olton DS (1989) Inferring psychological dissociations from experimental dissociations: the temporal context of episodic memory. In: Roediger HL & Craik FIM (eds) *Varieties of Memory and Consciousness,* Hillsdale, N.J.: Lawrence Erlbaum, p.161-177.

Olton D, Meck WH & Church RM (1987) Separation of hippocampal and amygdaloid involvement in temporal memory dysfunctions. *Brain Research* **404** 180-188.

Olton DS, Wenk GL, Church RM & Meck WH (1988) Attention and the frontal cortex as examined by simultaneous temporal processing. *Neuropsychologia* **26** 307-318.

Orme JE (1969) *Time, experience and behaviour.* London: Iliffe Books. 189pp.

Ornstein RE (1969) *On the experience of time.* Harmondsworth: Pengiun, 126pp.

Ostor A. (1993) *Vessels of Time: An essay on temporal change and social transformation.* Delhi: Oxford University Press. 103pp.

Owen GEL (1957) Zeno and the Mathematicians. *Proceedings of the Aristotelian Society* **58** 199.

Owen GEL (1979) Aristotle on Time. In Barnes J, Schofield M, Sorabji R. (eds) *Articles on Aristotle Vol. 3: Metaphysics.* London: Duckworth, p. 140-156.

Paivio A. (1978) Comparisons of Mental Clocks. *Journal of Experimental Psychology: Human Perception and Performance.* **4**, 61-71.

Paivio A, Yuille JC & Madigan SA (1968) Concreteness, imagery and meaningfulness values for 925 nouns. *Journal of Experimental Psychology Monograph Supplement* **76** 1 (2) 1-25.

Paller KA, Mayes AR, McDermott M, Pickering AD & Meudell PR (1991) Indirect measures of memory in a duration judgment task are normal in amnesic patients. *Neuropsychologia* **29** 1007-1018.

Pang D (1989) Physics and pathophysiology of closed head injury. In: Lezak MD (ed) *Assessment of the Behavioral Consequences of Head Trauma.* New York: Alan R Liss, p.1-17.

Pantelis C & Nelson HE (1994) Cognitive functioning and symptomatology in schizophrenia: the role of the fronto-subcortical systems. In: David AS & Cutting JC (eds) *The Neuropsychology of Schizophrenia* Hove: Lawrence Erlbaum, p.215-229

Pardo JV, Pardo PJ, Janer KW & Raichle ME (1990) The anterior congulate mediates processing selection in the Stroop attentional conflict paradigm. *Proceedings of the National Academy of Sciences* **87** 256-259.

Parkin AJ (1993) *Memory. Phenomena, experiment and theory.* Oxford: Blackwell, 231pp.

Parkin AJ (1996) *Explorations in Cognitive Neuropsychology.* Oxford: Blackwell, 288pp.

Parkin AJ (1997) (Ed) *Case Studies in the Neuropsychology of Memory.* Hove: Psychology Press 212pp.

Parkin AJ & Leng NRC (1993) *Neuropsychology of the Amnesic Syndrome.* Hove: Lawrence Erlbaum, 202pp.

Parkin AJ & Hunkin NM (1993) Impaired temporal context memory on anterograde but not retrograde tests in the absence of frontal pathology. Cortext **29** 267-280.

Parkin AJ, Leng NRC & Hunkin NM (1990) Differential sensitivity to context in diencephalic and temporal lobe amnesia. *Cortex* **26** 373-380.

Parkin AJ, Dunn JC, Lee C, O'Hara PF, Nussbaum L (1993) Neuropsychological Sequelae of Wernicke's Encephalopathy in a 20-year-old Woman: Selective Impairment of a Frontal Memory System. *Brain & Cognition* **21** 1-19.

Parkin A, Rees JR, Hunkin NM & Rose PE (1994) Impairment of memory following discrete thalamic infarction. *Neuropsychologia* **32** 39-51.

Passingham R (1993) *The Frontal Lobes and Voluntary Action.* Oxford: Oxford University Press. 299pp.

Pastor MA, Artieda J, Jahanshahi M & Obeso JA (1992) Time estimation and reproduction is abnormal in Parkinson's disease. *Brain* **115** 211-225.

Pastor JA & Artieda J (1996) Involvement of the basal ganglia in timing perceptual and motor tasks. In: Pastor JA & Artieda J (eds) *Time, Internl Clocks and Movement.* Amsterdam: Elsevier, p.235-255.

Patterson R (1990) Perceptual Moment Models Revisited. In Block RA (ed) *Cognitive Models of Psychological Time.* New York: Lawrence Erlbaum, p.85-100.

Petrides M, Milner B (1982). Deficits on subject-ordered tasks after frontal- and temporal-lobe lesions in man. *Neuropsychologia* **20** 249-262.

Posner MI & Rothbart MK (1991) Attentional mechansisms and conscious experience. In: Milner AD & Rugg MD (eds) *The neuropsychology of consciousness*. London: Academic Press, p.91-111.

Posner MI & Dehaene S (1994) Attentional networks. *Trends in Neurosciences*. **17** 75-79.

Power R.J.D & Longuet-Higgins H.S. (1978) Learning to count: A computational model of language acquisition. *Proceedings of the Royal Society of London*, **B200**, 391-417.

Pramstaller PP & Marsden CD (1996) The basal ganglia and apraxia. *Brain* **119** 319-340.

Prigatano GP (1995) The problem of lost normality after brain injury. *Journal of Head Trauma Rehabilitation* **10** 87-95.

Rabbitt P (1996) Why are studies of "prospective memory" planless? In: Brandimonte M, Einstein GO & McDaniel MA (eds) *Prospective Memory. Theory and Applications*. Mahwah, N.J.: Lawrence Erlbaum, p.239-248.

Rachman SJ (1974) Primary obsessional slowness. *Behaviour Research and Therapy* **12** 9-18.

Rachman SJ & Hodgson R (1980) *Obsessions and complusions*. Englewood Cliffs, N.J.: Prentice Hall, 435pp.

Rand MB, Trudeau MD & Nelson LK (1990) Reading assessment post head injury: how valid is it? *Brain Injury* **4** 155-160.

Rapp BC, Hillis AE & Caramazza A (1993) The role of representations in cognitive theory: more on multiple semantics and the agnosias. *Cognitive Neuropsychology* **10** 235-249.

Raven J.C. (1956) *Coloured Progressive Matrices*. London: H.K. Lewis.

Revelle W (1993) Individual differences in personality and motivation: 'non-cognitive'determinants of cognitive performance. In: Baddeley AD & Weiskrantz L (eds) *Attention: Selection, Awareness and Control*. Oxford: Clarendon Press, p.346-373.

Richards W (1973) Time reproductions by HM *Acta Psychologia* **37** 279-282.

Richardson JTE (1990) *Clinical and Neuropsychological Aspects of Closed Head Injury*. London: Taylor & Francis, 351pp.

Richardson JTE & Snape W (1984) The effects of closed head injury upon human memory: an experimental analysis. *Cognitive Neuropsychology* **1** 217-231.

Richter P & Benzehofer U (1985) Time estimation and chronopathology in endogenous depression. *Acta Psychiatrica Scandanavia* **72** 246-253.

Riddoch M.J. & Humphreys G.W. (1993) *Birmingham Object Recognition Battery.* Hove: Lawrence Erlbaum Associates.

Rimel RW, Giordani B, Barth JT, Boll TJ & Jane JA (1981) Disability caused by minor head injury. *Neurosurgery* **9** 221-228.

Roberts S & Holder MD (1984) What starts an internal clock? *Journal of Experimental Psychology: Animal Behavior Processes.* **10** 273-296.

Robinson AL, Heaton RK, Lehman RAW & Stilson DW (1981) The utility of the Wisconsin Card Sorting Test in detecting and localizing frontal lobe lesions. *Journal of Consulting and Clinical Psychology* **48** 605-614.

Robinson JP. (1988) Time-Diary Evidence about the Social Psychology of Everyday Life. In McGrath JE. (ed) *The Social Psychology of Time: New Perspectives.* Newbury Park, California: Sage Publications. p.134-148.

Roitblat HL & Young KNJ (1990) Time and Order: A Comparative Perspective. In Block RA (ed) *Cognitive Models of Psychological Time.* Hillsdale, N.J.: Lawrence Erlbaum, p.119-152.

Rousseau L & Rousseau R (1996) Stop-reaction time and the internal clock. *Perception and Psychophysics* **58** 434-448.

Rubin E. (1936) Some elementary time experiences. *Acta Psychologica* **1** 206-211.

Rueckert L & Grafman J (1996) Sustained attention deficits in patients with right frontal lesions. *Neuropsychologia* **34** 953-963.

Russell B (1915) On the experience of time. *Monist* **25** 212-233.

Russell WR (1932) Cerebral involvement in head injury: a study based on the examination of two hundred cases. *Brain* **55** 549-603.

Sacks O. (1973) Awakenings. London: Duckworth, 330pp.

Sagar HJ, Gabrieli JDE, Sullivan EV & Corkin S (1990) Recency and frequency discrimination in the amnesic patient HM *Brain* **113** 581-602.

Salmon P (1985) *Living in Time.* London: JM Dent & Sons, 152pp.

Sanders H. & Warrington E.K. (1971) Retrograde amnesia in organic amnesic patients. *Cortex* 11, 397-400.

Sawle GV, Hymas NF, Lees AJ & Frackowiak RSJ (1991) Obsessional slowness. Functional studies with positron emission tomography. *Brain* **114** 2191-2202.

Schank RC & Abelson RP (1977) *Scripts, plans, goals, and understanding.* Hillsdale, N.J.: Lawrence Erlbaum.

Schank RC & Abelson RP (1995) Knowledge and memory: the real story. In: Wyer RS (ed) *Knowledge and Memory: The Real Story.* Hillsdale, N.J.: Lawrence Erlbaum, p.1-85.

Schank R.C. (1982) *Dynamic Memory.* Cambridge: Cambridge University Press, 234pp.

Schank RC & Abelson RP (1995) Knowledge and memory: the real story. In: Wyer RS (ed) *Knowledge and Memory: The Real Story.* Hillsdale, N.J.: Lawrence erlbaum, p.1-85.

Schiffman N & Greist-Bousquet S. (1992) The effect of task interruption and closure on perceived duration. *Bulletin of the Psychonomic Society* **30** 9-11.

Schlesinger G. (1983) *Metaphysics* Oxford: Blackwell.

Schmitter-Edgecombe ME, Marks W, Fahy JF & Long CJ (1992) Effects of severe closed head injury on three stages of information processing. *Journal of Clinical and Experimental Neuropsychology* **14** 717-737.

Schnider A, von Daniken C & Gutbrod K (1996) Disorientation in amnesia. A confusion of memory traces. *Brain* **119** 1627-1632.

Scoville WB & Milner B (1957) Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery and Psychiatry* **20** 11-21.

Seddon K. (1987) *Time: A Philosophical Analysis.* London: Croom Helm.

Shallice T (1982) Specific impairments of planning. *Philosophical Transactions of the Royal Society of London.* **B298** 199-209.

Shallice T. (1988) *From Neuropsychology to Mental Structure.* Cambridge: Cambridge University Press.

Shallice T (1996) The neuropsychology of prospective memory. In: Brandimonte M, Einstein GO & McDaniel MA (eds) *Prospective Memory. Theory and Applications.* Mahwah, N.J.: Lawrence Erlbaum, p.319-325.

Shallice T & Burgess PW (1991) Deficits in strategy application following frontal lobe damage in man. *Brain* **114** 727-741.

Shallice T & Burgess PW (1993) Supervisory control of action and thought selection. In: Baddeley AD & Weiskrantz L (eds) *Attention: Selection, Awareness and Control.* Oxford: Clarendon Press, 171-187.

Shallice T. & Evans M.E. (1978) The involvement of the frontal lobes in cognitive estimation. *Cortex* **14** 294-303.

Shaw C & Aggleton JP (1994) The ability of amnesic subjects to estimate time intervals. *Neuropsychologia* **32** 857-873.

Sherover CM. (1971) *Heidegger, Kant and Time.* London: Indiana University Press, 322pp.

Shimamura AP, Janowsky JS & Squire LR (1991) What is the role of frontal lobe damage in memory disorders? In: Levin HS, Eisenberg HM & Benton AL (eds) *Frontal Lobe Function and Dysfunction.* New York: Oxford University Press, p.173-195.

Shimamura AP, Janowsky JS & Squire L (1990) Memory for the temporal order of events in patients with frontal lobe lesions and amnesic deficits. *Neuropsychologia* **28** 803-813.

Shoqeirat MA, Mayes A, MacDonald C, Meudell P & Pickering A (1990) Performance on tests sensitive to frontal lobe lesions by patients with organic amnesia: Leng & Parkin revisited. *British Journal of Clinical Psychology* **29** 401-408.

Shorter JM (1984) The reality of time. *Philosophia* **14** 321-339.

Shuren JE, Jacobs DH & Heilman KM (1997) Diencephalic temporal order amnesia. *Journal of Neurology, Neurosurgery and Psychiatry* **62** 163-168.

Siegal S & Castellan NJ (1988) *Nonparametric Statistics for the Behavioral Sciences.* (2nd ed.)New York: McGraw-Hill, 399pp.

Sims A (1995) *Symptoms in the Mind.* (2nd ed.) London: WB Saunders. 422pp.

Sirigu A & Grafman J (1996) Selective impairments within episodic memories. *Cortex* **32** 83-95.

Smart JJC (1955) Spatialising Time. Mind 64, reprinted as "Spatialising Time," in Gale R. (ed) *The Philosophy of Time,* London: Macmillan, p.163-167.

Smith NC (1969) The effect on time estimation of increasing the complexity of a cognitive task. *Journal of General Psychology* **81** 231-235.

Snowden J, Goulding PJ & Neary D (1994) Semantic dementia: autobiographical contribution to preservation of meaning. *Cognitive Neuropsychology* **11** 265-288.

Snowden JS, Griffiths HL & Neary D (1996) Semantic-episodic memory interactions in semantic dementia: implications for retrograde memory function. *Cognitive Neuropsychology* **13** 1101-1137.

Sokol S. M. & McCloskey, M. (1988) Levels of representation in verbal number production. *Applied Psycholinguistics.* **9,** 267-281.

Sorabji R (1979) Aristotle on the Instant of Change. In Barnes J, Schofield M, Sorabji R. (eds) *Articles on Aristotle Vol. 3: Metaphysics.* London: Duckworth.

Spikman JM, van Zomeren, Deelman BG (1996) Deficits of attention after closed head injury: slowness only? *Journal of Clinical and Experimental Neuropsychology* **18** 755-767.

Squire LR & Zola-Morgan S (1988) Memory: brian systems and behaviour. *Trends in Neurosciences* **11** 170-175.

Squire LR, Nadel L & Slater PC (1981) Anterograde amnesia and memory for temporal order. *Neuropsychologia* **19** 141-145.

Stevens M (1979) Famous personality test: a test for measuring remote memory. *Bulletin of the British Psychological Society* **32** 211.

Stevens SS. (1951) *Handbook of Experimental Psychology.* New York: Wiley. 1436pp.

Strange JR (1978) A Search for the Sources of the Stream of Consciousness. In Pope KS & Singer JL (eds) *The Stream of Consciouness.* New York: Plenum Press. p.9-29.

Stuss DT & Benson DF (1986) Neuropsychological studies of the frontal lobes. *Psychological Bulletin* **95** 3-28.

Summers JJ & Burns BD (1990) Timing in human movement sequences. In: Block RA (ed) *Cognitive Models of Psychological Time*. Hillsdale, N.J.: Lawrence Erlbaum, p.181-206.

Takeuchi T, Nakagawa A, Harai H, Nakatani E, Fujikawa S, Yoshizato C & Yamagami T (1997) Primary obsessional slowness: long-term findings. *Behaviour Research and Therapy* **35** 445-449.

Talland G (1965) Amnesia: a world without continuity. In: *Readings in Psychology Today* Del Mar, California: CRM Books, p.268-275.

Tayama T (1987) Models for time perception and time estimation. *Japanese Psychological Review.* **30** 423-451.

Taylor R (1990) Relationships between cognitive test performance and everyday cognitive difficulties in multiple sclerosis. *British Journal of Clinical Psychology* **29** 251-252.

Taylor R & O'Carroll R (1995) Cognitive estimation in neurological disorders. *British Journal of Clinical Psychology* **34** 223-228.

Thomas EAC & Cantor NE (1975) On the duality of simultaneous time and size perception. P*erception and Psychophysics* **18** 44-48.

Thomas EAC & Weaver WB (1975) Cognitive processing and time perception. *Perception and Psychophysics* **17** 363-367.

Thomas EAC & Cantor NE (1978) Interdependence between the processing of temporal and non-temporal information. In: Requin J (ed) *Attention and Performance VII.* Hillsdale, N.J.: Lawrence Erlbaum, p.43-62.

Titchener EB (1905) *Experimental Psychology.* London: Macmillan. 453pp.

Toates F (1992) *Obsessive Compulsive Disorder.* London: Thomsons, 192pp.

Todd R. R., Barber P. J., & Jones D (1987) The internal representation of number: analogue or digital? In Sloboda J.A., & Rogers D (Eds.) *Cognitive Processes in Mathematics.* Oxford: Clarendon Press.

Toulmin S & Goodfield J (1967) *The Discovery of Time.* Harmondsworth: Pelican, 219pp.

Treisman M (1963) Temporal discrimination and the indifference interval: Implications for a model of the "internal clock." *Psychological Monographs* **77** 1-31.

Treisman M, Faulkner A, Naish PLN, Brogan D. (1990) The internal clock: Evidence for a temporal oscillator underlying time perception with some estimates of its characteritic frequency. *Perception* **19** 705-743.

Treisman M,Faulkner A, Naish PLN (1992) On the Relation Between Time Perception and the Timing of Motor Action: Evidence for a Temporal Oscillator Controlling the Timing of Movement. *The Quarterly Journal of Experimental Psychology* **45A** 235-263.

Treisman M, Cook N, Naish PLN, MacCrone JK (1994) The internal clock: Electroencephalographic evidence for oscillatory processes underlying time perception. *Quarterly Journal of Experimental Psychology* **47A** 241-289.

Troncoso JC & Gordon B (1996) Neuropathology of closed head injury. In: Rizzo M & Tranel D (eds) *Head Injury and Post-concussive Syndrome.* New York: Churchill Livingstone, p.47-56.

Tsang PS, Velazquez VL, Vidulich MA (1996) Viability of resource theories in explaining time-sharing performance. *Acta Psychologica* **91** 175-206.

Tsukanov BI (1991) The quality of an "inner clock" and intelligence. *Soviet Journal of Psychology* **12** 34-42.

Tulving E (1983) *Elements of Episodic Memory.* Oxford: Clarendon Press, 351pp.

Tulving E (1987) Multiple memory systems and consciousness. *Human Neurobiology* **6** 67-80.

Tulving E & Donaldson E (1972) *Organization of Memory.* New York: Academic Press.

Tuokko H, Hadjistavropoulos T, Miller JA & Beattie BL (1992) The clock test: a sensitive measure to differentiate normal elderly from those with Alzheimer disease. *Journal of the American Geriatrics Society* **40** 579-584.

Tyerman AD (1987) Self concept and psychological change in the rehabilitation of the severely head injured person. Unpublished PhD dissertation, London: University of London.

Tysk L (1983a) Time estimation by healthy subjects and schizophrenic patients: a methodological study. *Perceptual and Motor Skills* **56** 983-988.

Tysk L (1983b) Estimation of time and the subclassification of schizophrenic disorders. *Perceptual and Motor Skills* **57** 911-918.

Tysk L (1984) A longitudinal study of time estimation in psychotic disorders. *Perceptual and Motor Skills* **59** 779-789.

Tysk L (1985) Longitudinal changes in time estimation in affective disorders: a preliminary study. *Perceptual and Motor Skills* **60** 179-188.

Tzeng OJL, Lee AT & Wetzel CD (1979) Temporal coding in verbal information processing. *Journal of Experimental Psychology. Human Learning and Memory.* **5** 52-64.

Underwood BJ (1966) *Experimental Psychology* (2nd edition) New York: Appleton-Century-Crofts.

Underwood G. & Swain R. (1973) Selectivity of attention and the perception of duration. *Perception* **2** 101-105.

Vakil E, Blachstein H & Hoofien D (1991) Automatic temporal order judgment: the effect of intentionality of retrieval on closed-head-injured patients. *Journal of Clinical and Experimental Neuropsychology* **13** 291-298.

Van Dijk TA & Kintsch W (1983) *Strategies of discourse comprehension.* New York: Academic Press.

Van der Linden M, Coyette F & Seron X (1992) Selective Impairment of the "central executive" component of working memory: a single case study. Cognitive Neuropsychology **9** 301-326.

Vanderplas JM & Garvin EA (1959) The association value of random shapes. *Journal of Experimental Psychology* **57** 147-154.

Vorberg D & Hambuch R (1984) Timing of two-handed rhythmic performance. In: Gibbon J & Allan L (eds) *Timing and Time Perception.* New York: New York Academy of Sciences.

Vroon PA (1970) Effects of presented and processed information on duration experience. *Acta Psychologica* **34** 115-121.

Wahl OF & Sieg D (1980) Time estimation among schizophrenics. *Perceptual and Motor Skills.* **50** 535-541.

Wang PL (1987) Concept formation and frontal lobe function. In: Perecman E (ed) *The Frontal Lobes Revisited.* New York: IRBN Press, p.189-205.

Warnock M (1987) *Memory.* London: Faber & Faber, 150pp.

Warrington E.K. (1975) The selective impairment of semantic memory. *Quarterly Journal of Psychology* **27** 635-657.

Warrington E.K. (1984) *Recognition Memory Test.* Windsor: NFER-Nelson.

Warrington E.K. & McCarthy R.A. (1988) The Fractionation of Retrograde Amnesia. *Brain and Cognition* **7** 154-200.

Warrington E.K. & James M. (1991) *The Visual Object and Space Perception Battery.* Bury St Edmunds: Thames Valley Test Co.

Warrington EK, James M & Maciejewski C (1986) The WAIS as a lateralising and localising diagnostic instrument: a study of 656 patients with unilateral cerebral lesions. *Neuropsychologia* **24** 223-239.

Watt JD (1991) The effect of boredom proneness on time perception. *Psychological Reports* **69** 323-327.

Watts FN & Sharrock R (1984) Fear and time estimation. *Perceptual and Motor Skills* **59** 597-598.

Wearden JH & Penton-Voak IS (1995) Feeling the heat: body temperature and the rate of subjective time. *Quarterly Journal of Experimental Pychology* **48B** 129-141.

Weddell R.A. & Davidoff J.B. (1991) A Dyscalculic patient with selectively impaired processing of numbers. *Brain and Cognition* **17,** 240-271.

Weinberger DR, Berman KF & Daniel DG (1991) Prefrontal cortex dysfunction in schizophrenia. In Levin HS, Eisenberg HM & Benton AL (eds) *Frontal Lobe Function and Dysfunction.* New York: Oxford University Press, p.275-287.

Welsh JP, Lang EJ, Suglhara I & Llanas R (1995) Dymanic organisation of motor control within the olivocerebellar system. *Nature* **374** 453-457.

Westman AS (1987) Development of time concepts: differentiating clock and calendar from apparent durations. *Journal of Genetic Psychology* **148** 259-270.

Whitrow GJ. (1972) *The Nature of Time.* Harmondsworth, Middlesex: Pengiun, 153pp.

Whitrow GJ. (1987) *The Natural Philosophy of Time* (2nd edition) Oxford: Clarendon Press, 399pp.

Whitrow GJ (1988) *Time in History.* Oxford: Oxford University Press. 217pp.

Wiegersma S, van der Scheer, & Hijman R (1990) Subjective ordering, short term memory, and the frontal lobes. *Neuropsychologia* **28** 95-98.

Williams DC. (1951) The Myth of Passage. Journal of Philosophy 48, reprinted as "The Myth of Passage" in Gale R. (ed) *The Philosophy of Time,* London: Macmillan, p. 98-116.

Williams HG, Woollacott MH, Ivry R (1992) Timing and motor control in clumsy children. *Journal of Motor Behavior* **24** 165-172.

Williams JM, Medwedeff CH & Haban G (1989) Memory disorder and subjective time estimation. *Journal of Clinical and Experimental Neuropsychology* **11** 713-723.

Williams JMG, Ellis NC, Tyers C, Healy H, Rose G & MacLeod AK (1996) The specificity of autobiographical memory and imageability of the future. *Memory and Cognition* **24** 116-125.

Wilson B, Cockburn J, Baddeley A. The Rivermead behavioural memory test. Reading, Berks: Thames Valley Test Company, 1985.

Wilson B., Cockburn J. & Halligan P. (1987) Development of a behavioural test of visuo-spatial neglect. *Archives of Physical Medicine and Rehabiliation.* **68,** 98-102.

Wilson BA, Baddeley AD & Kapur N (1995) Dense amnesia in a professional musician following herpes simplex virus encephalitis. *Journal of Clinical and Experimental Neuropsychology* **17** 668-681.

Wilson JTL (1990) The relationship between neuropsychological function and brain damage detected by neuroimaging after closed head injury. *Brain Injury* **4** 349-363.

Wilson JTL, Teasdale GM, Hadley DM, Wiedmann & Lang D (1993) Post-traumatic amnesia: still a valuable yardstick. *Journal of Neurology, Neurosurgery and Psychiatry* **56** 198-201.

Wilson RS, Koller W, & Kelly MP (1980) The amnesia of transient global amnesia. *Journal of Clinical Neuropsychology* **2** 259-266.

Winer BJ (1971) *Statistical Principles in Experimental Design*. Tokyo: McGraw-Hill.

Wing AM & Kristofferson AB (1973) Response delays and timing of discrete motor responses. *Perception and Psychophysics* **14** 5-12.

Wood R Ll (1990) *Neurobehavioural Sequelae of Traumatic Brain Injury*. London: Taylor & Francis, 359pp.

Woodworth RS & Schlosberg H. (1954) *Experimental Psychology*. New York: Holt. 948pp.

Yntema DB & Trask FP (1963) Recall as a search process. *Journal of Verbal Learning and Verbal Behavior.* **2** 65-74.

Zabrodin YM, Borozdina LV & Mousina IA (1983) Time estimation as a function of anxiety level. *Vestnik Moskovskogo Universiteta Seriya Psikhologiya* **4** 46-53.

Zakay D (1990) The Evasive Art of Subjective Time Measurement: Some Methodological Dilemmas. In Block RA (ed) *Cognitive Models of Psycholgocial Time*. Hiilsdale, N.J.: Lawrence Erlbaum. p.59-84.

Zakay D (1992) On prospective time estimation, temporal relevance and temporal uncertainty. In: Macar F, Pouthas V & Friedman WJ (eds) *Time, Action and Cognition*. Dordrecht: Kluwer Academic, p.109-117.

Zakay D (1993a) Time estimation methods - do they influence prospective duration estimates? *Perception* **22** 91-101.

Zakay D (1993b) Relative and absolute duration judgments under prospective and retrospective paradigms. *Perception and Psychophysics* **54** 656-664.

Zakay D, Tsal Y, Moses M & Shahar I (1994) The role of segmentation in prospective and retrsopective time estimation processes. *Memory and Cognition* **22** 344-351.

Zakay D & Block RA (1996) The role of attention in time estimation processes. In: Pastor MA & Artieda J (eds) *Time, Internal Clocks and Movement*. Amsterdam: Elsevier, p.143-164.

Zwaagstra R, Schmidt I & Vanier M (1996) Recovery of speed of information processing in closed head injury patients. *Journal of Clinical and Experimental Neuropsychology* **18** 383-393.

Zwart PJ (1976) *About time.* Amsterdam: North-Holland, 266pp.

Previous research in this area has investigated task manipulations which produce mainly under-estimates of duration by the method of verbal estimation (or over-estimates by the method of time production). Indeed, chapters 6, 7, 9 and 10 contain information reported in this fashion (as a time distortion ratio - ψ/t). However, although this index of timing ability was inspected in each study, it rarely showed significant differences between subjects. In fact, there are good grounds for understanding why this was so, and for justifying the use of timing accuracy as the primary dependent variable in the present research.

The use of under/over-estimation of duration is based on several key assumptions: (1) the research subjects are a homogenous group (from the same population); (2) they are normally reasonably (or equally) *accurate* in their timing; (3) to the extent that the only effect of task manipulations will be to detract attention away from time, such manipulations will yield under-estimates of duration; (4) the degree of under-estimation of time therefore equates to timing accuracy.

It is contended that none of these assumptions is valid for the present research on the following grounds. (1) The subjects are clearly not from the same population and therefore would not be expected to behave in similar fashion. (2) As two of the three groups are severely brain injured, one cannot assume that these groups will be accurate in their timing. (3) The effect of task manipulations cannot be guaranteed to produce under-estimates of time, as there is no a priori reason to believe that subjects would be accurate. They might not take notice of changes in task demands, or they might initially over-estimate duration to such an extent that even a reduced estimated duration could still represent an over-estimate (and potentially a more accurate estimate). (4) Finally, because one has to allow for the likelihood of disturbed timing, including over-estimates of time, time estimation accuracy cannot simply be equated with degree of under-estimation.

A note on the use of ANOVA is useful at this point, in order to clarify the rationale for using this technique as the principal statistical method. It is well recognised that a test for the equality of two or more sample variances can be used to test the equality of the sample means, and, furthermore, that such a method is preferable if more than two groups are being compared. Nonetheless the use of ANOVA strictly entails three assumptions. First, it is to be assumed that the observations in each group are normally distributed. Exploratory data analysis involving tests for normality (eg. Shapiro-Wilk test) did not justify rejection of this assumption. Second, ANOVA assumes that the observations are independent of one another (unless a repeated measures design is used). In the present research, this is also a valid assumption for those data which are subject to ANOVA, as the three groups of subjects are clearly independent.

Finally, it is commonly stated that the use of ANOVA requires the population variances of each group to be the same. Yet, as stated above, in many chapters in the thesis the sample variance of the control group is exceeded by the variance of the very severe head injury group, thus violating the homogeneity of variance assumption. Fortunately, in most such circumstances ANOVA is fairly robust and will tolerate departures from normality and homogeneity (Everitt,1996). Where the departures from these assumptions are considered too extreme, then Everitt (1996) suggests a transformation of the data, such as logarithm transformation. In the present research this conservative approach was adopted and the raw theta values (representing time estimation accuracy) were log. transformed prior to analysis. In such circumstances the data are reported in their original form.

In order to discover whether the variables of head injury and temporal coherence *considered together* have any meaningful bearing on estimated duration, a multivariate analysis of variance (MANOVA) is indicated. This permits examination of whether there are any between-group disparities in the way different groups of subjects respond to the two tasks. Indeed, when the data were subject to such an analysis, there was a strong hint of just such an interaction ($F = 2.51$ (59) $p > .05$). Although the effect is strictly not demonstrable at a conventional level of statistical significance, the magnitude of the trend is such that one might, in an exploratory study, interpret it as a possible effect worthy of further investigation. This would seem to suggest that individuals are more prone to inaccuracies of prospective timing in the less temporally coherent story.

A MANOVA was conducted on all theta values from all subjects in the Error and Non-Error lexical decision tasks. This was to determine whether there was any combined effect of the nature of the tasks and the presence of head injury upon estimated duration. However, the results failed to show any signs of such an interaction. One may assume therefore that the judgements of time made by head injured subjects were not any more sensitive to the changes in task than were those made by non-head injured controls. A second MANOVA on the data from the No-Error and Interrupted versions of the lexical decision task also showed there was no effect of head injury on timing accuracy. However, in contrast, on the information processing task, which was four minutes' duration compared to the two minute length of the lexical decision task, there was indication of just such an interaction. Thus a MANOVA on the data from all subjects for the interrupted and non-interrupted information processing tasks showed that head injured subjects were particularly prone to reduced timing inaccuracy in the interrupted condition ($F = 3.26$ (29) $p < .05$).

Independent ANOVAs suggested that the controls and head injured subjects were both marginally less accurate in judging time under the more demanding task (the complex card sort condition). In order to ascertain whether there was any combined effect of head injury and task complexity upon estimated duration, the data were subject to a MANOVA. This revealed that there was no significant interaction effect ($p < 2$) although the trend could be eagerly interpreted as suggesting that timing after a head injury is particularly sensitive to disruption by changes in task demands (in this case, sorting complexity). However, such an interpretation is clearly highly speculative and serves only to highlight a tentative hypothesis in need of more substantial investigation.

Caution should be expressed at this point about the interpretation of these data, as the analyses are exploratory. In particular, one should consider how the data as described in section 14.2(i) violate certain assumptions about the sampling distribution necessary for linear regression.

The main caveat in understanding figures 14.1, 14.2 and 14.3 is that the data are not independent. For example, figure 14.1 depicts the theta values for each subject on non-interrupted, prospectively estimated tasks reported in chapters 4, 5, 6 and 7. Figures 14.2 and 14.3 illustrate the same information separately for controls and head injured subjects respectively. As the data involve several observations from each subject one cannot correlate timing accuracy with task duration. The figures merely serve to summarise the data from studies reported in previous chapters along a continuum of task duration.

A similarly conservative approach needs to be taken with regard to the putative 'regressions' depicted in figures 14.4, 14.5 and 14.6. Again, the observations are not mutually independent, and the notion of constant variability at each point along the data is clearly untenable, given the sample heterogeneity. Given such limitations to the data one cannot take the regressions as indicating a statistically robust relationship between timing and task duration. The suggestion of any such relationship is clearly speculative and is only included because there has not been any attempt to test such a hypothesis previously. At best however, such an interpretation must remain guarded, not only because the data violate assumptions required for meaningful regression analysis, but also on account of the limited range of durations explored. Extrapolation to time intervals beyond these parameters would be unwise at this stage.