Speech processing and short-term memory in children with normal and atypical speech and language development

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Submitted for the degree of Doctor of Philosophy,
December 2000.

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Margaret Vance, Department of Human Communication Science,
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ABSTRACT

This thesis is motivated by research evidence of significant relationships between short-term memory and speech and language development, and by clinical observations of poor short-term memory skills in some children with developmental language difficulties. It addresses the question 'to what degree do speech processing skills underpin short-term memory and language development'? A series of experiments were carried out, collecting data from children, aged 7 years and under, who were developing normally, and from children with speech and / or language difficulties.

Performance on tasks of speech production and auditory discrimination were found to show significant developmental differences, and these speech processing skills were significantly correlated with non-word repetition performance. Different presentation and response mechanisms, and the phonological complexity of words to be recalled significantly affected short-term memory performance. These findings implicate speech input and output processing in short-term memory performance. Data from a longitudinal study showed that auditory discrimination skills significantly predicted the development of both short-term memory and receptive language development, but speech production skills were not related to

short –term memory or language development. Short-term memory skills significantly predicted grammatical development.

A series of case studies of children with speech and / or language difficulties demonstrated a range of individual, longitudinal profiles of performance across speech processing, short term memory and standardised language measures. Findings from the normative data did not explain the patterns of development in clinical cases, however, short-term memory skills were broadly in line with the level of receptive language development attained. Relationships between short-term memory, speech and language in normal development may not reflect the mechanisms by which short-term memory and language is impaired in disordered individuals.

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CHAPTER 1:
SHORT-TERM MEMORY AND LANGUAGE DEVELOPMENT

1.1 INTRODUCTION

The aim of this thesis is to investigate the relationship between short-term memory, language development and speech processing skills in normal and atypical development. The first two chapters of this report will consider the theoretical background to short-term memory and to speech processing. Research findings into possible relationships between short-term memory and language development, and between short-term memory and speech processing skills will be discussed. Chapter 3 will present an experiment in which the speech processing skills of young children are assessed. A developmental perspective is taken. Chapter 4 will further analyse data from the first experiment to allow particular exploration of non-word repetition skills. Chapter 5 will present an experiment using short-term memory tasks with young children. It will contrast recall of stimuli with a simple phonological structure with recall of those with a more complex structure. Different presentation and response modalities are used to allow the speech processing demands tasks to be compared. Chapter 6 will present data from a longitudinal study of a group of young children who are developing normally. The measures used include tasks of short-term memory, speech processing and language skills. Chapter 7 will present the individual profiles of a number of children with speech and / or language difficulties showing performance on short-term memory, speech processing and language measures. Chapter 8 will discuss the findings of the study, and present conclusions about the relationship between speech processing, short-term memory and language development.

Short-term memory capacity is considered to affect the ability to process language. For example, Cowan (1996) discusses the role of short-term memory in understanding language, "it is impossible to comprehend a word within conversation without keeping in mind the necessary background information established by prior words in the sentence, and often by preceding sentences" (p. 1). However, adults with acquired short-term memory deficits do not seem to have a problem with language comprehension (as in the case described by Baddeley, Papagno & Vallar, 1988).

A number of studies have identified relationships between the development of short-term memory and of language (e.g. Adams & Gathercole, 1995, 1996). It has been suggested that one role for the phonological loop within the working memory model is to support language learning (Baddeley, Gathercole & Papagno, 1998). Some of the evidence for this suggestion comes from findings of strong correlational relationships between short-term memory span and language measures in children. However it is also possible that some speech processing or cognitive factors underpin the development of both short-term memory and language.

The purpose of this first chapter is to consider the theoretical background to short-term memory and to explore research findings of the relationship between short-term memory and language development.

Firstly a model of short-term memory, the working memory model (Baddeley & Hitch, 1974), will be explored.
Secondly research findings will be discussed that focus on the relationship between short-term memory and

- vocabulary development.

- grammatical development.
- second language learning.
- developmental language disorder.

1.2 SHORT-TERM MEMORY

Short-term memory (STM) is defined by Baddeley (1999) as "a system for storing information over brief intervals of time" (p. 21). The information retained may be directly recalled in some way and / or be required for performance of an on-going task. Early STM research focussed on span tasks. Participants listened to lists of numbers or words, and immediately recalled them. A consistent finding is that most adults can recall six or seven items (Baddeley, 1999). However, research by Brown (1958) and Peterson and Peterson (1950) (cited in Baddeley, 1999) showed that lists of items would be recalled poorly if participants were given a task to perform between presentation and recall. It was inferred that this intervening task prevented participants from rehearsing the items to be recalled. These two features of limited capacity and loss of information unless material is actively rehearsed characterise the phenomenon of STM.

1.2.i Working Memory

One influential model of how STM might function is the working memory (WM) model, first described by Baddeley and Hitch (1974). The term WM is used for this system which involves the "temporary processing and storage of information" (Gathercole & Baddeley, 1993 p. 2), for cognitive tasks, including language comprehension and long-term learning. The WM model accounts for the findings of limited capacity and need for rehearsal. It has been the focus of much of the more recent research into STM. The model proposes three components to the STM system. A core system is

considered to control the overall system, and this is called the central executive. Two slave systems are described, the visuo-spatial sketch pad and the phonological loop. The central executive is viewed as "a limited capacity attentional system that controls the phonological loop and sketch pad, and relates them to long term memory" (p. 66 Baddeley, 1999). It is a complex system involved in the processing of the information that is being retained in STM, but is not yet fully explored or understood. The visuo-spatial sketch pad is involved in the short-term retention of visual and spatial information. The phonological loop is considered to be the system specialised for the maintenance of speech-based material in STM. This component of the WM model is a main focus for the current study.

1.2.ii The Phonological Loop

The phonological loop consists of a phonological store in which material to be remembered is held in a phonological code, and a sub-vocal rehearsal process whereby material held in the store is recoded and refreshed (see Figure 1.1). The rehearsal mechanism is viewed as an integral part of this model. The material in the phonological store is considered to be subject to decay over time. The sub-vocal rehearsal process refreshes this material, allowing it to be maintained for longer within the loop. Research findings have suggested that the capacity of the phonological loop is the amount of spoken material that an individual can articulate within about 1.5 seconds (Baddeley, 1999). Hulme and MacKenzie (1992) suggest that performance on STM tasks will be a function of the length of each item of material presented and the rate of articulation.

There is evidence to suggest that the phonological loop is implicated in the recall of some visual material, such as written words or pictures (Hitch, Halliday, & Littler, 1989b, Hitch, Woodin & Baker, 1989c). The model

therefore allows for non-speech input to be coded in a speech based form through the sub-vocal rehearsal process. Visual stimuli can then be maintained and rehearsed within the phonological loop in the same way as speech stimuli. The recall of picture material will be further discussed in Chapter 5.

Figure 1.1: Model of the phonological loop, taken from Gathercole and Baddeley (1993).

The Subvocal Rehearsal Process

One major area of investigation into the functioning of the phonological loop has focussed on word length effects. A robust finding, that has been replicated in a number of studies, is that people can recall fewer longer words than shorter words (Baddeley, Thomson & Buchanan, 1975). The *word length effect* is thought to reflect the limited capacity of the rehearsal process, in that longer words take longer to say and so will take up more time within the subvocal rehearsal process. Shorter words can be articulated more quickly and so more short words can be rehearsed, and, therefore, maintained in the phonological store. The word length effect will be examined further in Chapter 5.

Other evidence for the subvocal rehearsal process comes from experiments in which participants were required to repeat something other than the stimuli to be recalled, e.g. "the, the, the", between presentation and recall. In this condition, participants can recall fewer visually presented stimuli (Murray, 1965, cited in Baddeley, 1986) and the word length effect is reduced (Baddeley, 1992). This *concurrent speech effect*, also known as articulatory suppression, is considered to prevent participants from using the subvocal rehearsal process. They are unable to verbally code visually presented material and to rehearse this or spoken stimuli.

The Phonological Store

Another phenomenon that appears to interfere with the verbal coding of visual stimuli is the *unattended speech effect*. Here irrelevant spoken material is presented at the same time as auditory or visual stimuli are presented for recall. Although participants were instructed not to attend to the irrelevant material, recall was impaired (Salame & Baddeley, 1982 and Hanley & Broadbent, 1987, cited in Hulme & MacKenzie, 1992). Baddeley (1999) argues that the unattended, or irrelevant, speech disrupts recall because it gains obligatory access to the phonological store and corrupts the memory trace.

Another robust finding in STM research is of a *phonological similarity effect*. Recall of a list of stimuli that sound similar is poorer than for an equivalent list of stimuli that do not sound similar (Conrad & Hull, 1964, cited in Gathercole & Baddeley, 1993). The disruption to recall is considered to occur within the phonological store (Gathercole & Baddeley, 1993) because as the phonologically coded material degrades and loses definition, it is more easily confusable with other material that is phonologically similar than with material that is dissimilar.

The Phonological Loop in Development

The word length effect has been found in children's recall (Hulme, Thomson, Muir & Lawrence, 1984, Hulme & Tordoff, 1989, Hitch et al., 1989c, Henry & Millar, 1991). There is also evidence for the phonological similarity effect (Halliday, Hitch, Lennon & Pettipher, 1990, Hulme 1987), and the concurrent speech effect (Hitch et al., 1989b, Henry, 1991a) to be operating in children's STM performance. However, these effects are less marked in younger children and there is some debate about whether a subvocal rehearsal process is operating early in development (e.g. Gathercole & Hitch, 1993). This issue will be further discussed in the next chapter (Chapter 2).

1.2.iii Working Memory and Short-term Memory

Hulme and Roodenrys (1995) acknowledge that the term WM is being used in different ways and define WM as "the system (or more accurately set of systems) responsible for the temporary storage of information during the performance of cognitive tasks" (p. 374). Hulme and Mackenzie (1992) discuss how "the importance of the concept of WM as a functional term needs to be distinguished from the adequacy of the Baddeley and Hitch model as a structural model, used to account for many STM phenomena" (p. 22).

Swanson (1993) defines STM as a "small amount of material held passively and then reproduced in untransformed fashion" (p. 87), whilst WM is defined as holding "a small amount of material in mind for a short time, while simultaneously carrying out further operations" (p. 87). This view is in accord with Oakhill and Kyle (1999) who suggest that WM tasks require storage and processing, but STM tasks just require storage.

Dempster (1985, cited in Henry & Millar, 1993), however, assumes STM and WM to be equivalent.

One interpretation to consider is that within the WM model the phonological loop component is involved in STM task performance, whereas WM tasks will additionally involve the central executive component. Within this study the memory measures used will require untransformed recall of visually and verbally presented stimuli. The measures used are, therefore, considered to be measures of STM and not of WM.

Researchers have more recently made use of the terms phonological memory, phonological short-term memory and phonological working memory. For example, Gathercole and Martin (1996) use the term phonological short-term memory (PSTM) to refer to the retention of "sequences of verbal material over short periods of time" (p. 73). Phonological memory seems, therefore, to imply the use of the phonological loop of the WM model.

1.3 STM AND LANGUAGE DEVELOPMENT

Experimental evidence supports the view that there is a relationship between the development of STM capacity and the development of language skills. However, different research methodologies have been used, and the measures of STM capacity vary. There is also some debate about the nature of the relationship. It is not clear whether increased STM capacity drives further language development, or whether STM capacity is governed by the level of language development. It is also possible, that

both STM capacity and language are related because other cognitive processes underlie development of both these skills.

1.3.i STM and Vocabulary Development

The aspect of language development that has been most researched in regard to STM is vocabulary development. Robinson, Dale and Landesman (1990, cited in Speidel 1993) found that pre-school children with precocious expressive vocabulary also scored very highly on a sentence repetition task, suggesting that verbal STM was also exceptionally well developed. Two other measures of STM have been used in the research in this area. These are non-word repetition (NWR) and word or digit span. For the NWR task the experimenter says some made-up (or non-) words, one at a time, and the participant repeats each stimuli. Performance score is usually based on the accuracy of the production of the non-word. For span tasks, the experimenter presents spoken lists of words for the participant to repeat. The lists are short to begin with and increase by one item at a time until the participant is unable to recall all the items in the list. Performance score may be for the maximum list length correctly recalled, with each item in the correct serial order. However, some researchers score for free recall, i.e. the number of items recalled without regard for the serial order.

A large body of work considering relationships between STM and vocabulary development has been carried out by Gathercole and colleagues. Gathercole, Willis, Emslie and Baddeley (1992) analysed longitudinal data from a group of children tested at 4, 5, 6 and 8 years of age. They found that phonological memory, as tested using a NWR task, was significantly correlated with vocabulary skills at ages 4, 5, and 6 years. A digit span task was only used with the two oldest groups and was significantly correlated with vocabulary at ages 6 and 8 years. These

correlations held when age and IQ were partialled out. Cross-lagged correlations between adjacent age groups, with age, IQ and earlier scores partialled out of the analyses, showed that NWR at age 4 was significantly more strongly correlated with vocabulary at age 5 years, than vice-versa. This suggested that NWR skills (interpreted by Gathercole et al. (1992) to be phonological memory skills) play a causal role in vocabulary development. Between the ages of 5 and 6 years, the reverse relationship was found. Vocabulary knowledge at 5 years was significantly more strongly correlated with NWR at 6 years than vice versa, the same pattern occurring between 6 and 8 years. This suggests that for these older age groups it is vocabulary knowledge that supports NWR. Gathercole et al. (1992) propose that "children with good phonological memory abilities produce phonological memory traces that are highly discriminable and persistent and that, as a consequence, there is a greater probability for these children that any particular phonological trace will a) become a long term durable phonological trace and b) link semantically with its referent" (p. 896). They also propose that "beyond 5 years of age children's linguistic knowledge, as indexed by their vocabulary scores, exerts an important causal influence on their performance on phonological STM measures" (p. 896).

A study by Gathercole and Baddeley (1990a) explored the STM / vocabulary development relationship by looking at how quickly children learned new words. Children aged 5 years old were split into two groups, on the basis of their NWR performance. One group had performed well on a NWR task and the other group had performed poorly. The children were shown toy animals and told the names assigned to them. The names were either familiar names or non-word names. The tester named each toy and the child repeated the name, this was continued until the child repeated the

name correctly. Children were than asked to recall the name for each toy. The group of children who had performed less well on NWR took significantly longer to learn the non-word names than the children with high NWR scores, and delayed recall of the names was also significantly poorer. This study seems to indicate that children who are better at repeating non-words, are quicker to learn vocabulary and retain it for longer. Gathercole and Baddeley (1990a) consider NWR to primarily reflect phonological memory skills and that "phonological memory plays an important role in the long-term phonological learning" (p. 450). They suggest that, for the group of children with poorer NWR skills, encoding of the new phonological form may be 'more noisy', or less strongly specified, or the temporarily stored material may decay more rapidly. These less adequate phonological representations may prevent longer term learning of the phonological form.

In 5 year-olds NWR and non-word memory span (single syllable) was significantly correlated with existing receptive vocabulary and the ability to recognise and produce newly learnt words, that were explicitly taught (Michas & Henry, 1994). Michas and Henry support Gathercole and Baddeley's (1989, 1990a) hypothesis, in suggesting that "phonological memory is required to help establish a long-term phonological representation for new words" (p. 160). The relationship between NWR and non-word span and vocabulary learning was not significant when the experimental condition was incidental word learning. Michas and Henry (1994) also conclude that as age, spatial memory and the non-word measures only accounted for between 23% and 26% of the variation in vocabulary or word learning, other cognitive and environmental factors are likely to play a role.

Further evidence for a relationship between STM and receptive vocabulary comes from Adams, Bourke and Willis (1999). In this study, a composite score of NWR and word and digit span was found to account for 10% of the additional variance in receptive vocabulary scores after age, non-verbal skills, and measures of visual memory and central executive functioning had been accounted for.

In a study of productive vocabulary, Adams and Gathercole (1995) measured the number of different vocabulary items that occurred in 3 year-old children's spontaneous speech. Analyses showed that children who had performed less well on tasks of NWR and digit span used significantly fewer different words in their utterances, than children who had performed better on NWR and digit span. Adams and Gathercole (1995) conclude that this supports the view that the phonological loop is critical to language learning and to the acquisition of new vocabulary.

Avons, Wragg, Cupples and Lovegrove (1998) found a significant relationship between NWR and vocabulary development in 5 year-old children, but not in 6 year-old children. NWR at 5 years did not predict vocabulary development a year later. This is contrary to the findings of Gathercole et al.'s (1992) study. Avons et al. (1998) suggest one reason for this difference may lie in the use of a slightly different presentation of the NWR task, in that Avons et al. only allowed 3 seconds for the children to repeat the non-words, whereas Gathercole et al. allowed unlimited time.

Vocabulary Development and Non-Word Repetition

From a speech processing perspective the relationship between NWR and vocabulary development found in some of these studies (Gathercole & Baddeley, 1990a, Gathercole et al., 1992, Michas & Henry, 1994), is

unsurprising. Both NWR and new word learning, which underpins vocabulary development, involve very similar levels of speech processing. The NWR task will be more fully described and discussed in Chapters 3 and 4. However, both NWR and new word learning will involve the following speech processing levels:

- The perception of components of unfamiliar verbal material.
- The creation of new motor programs for unfamiliar strings.
- Speech output articulatory skills.

The only difference is in the nature of the representation of the new strings of phonological material, either as a temporary representation in the case of NWR, or as a more permanent representation, for new word learning and vocabulary development. This would lead one to expect that correlations between NWR and measures of vocabulary and new word learning would be consistently strong. Whilst Gathercole and Baddeley's hypotheses about the role of the quality and durability of temporary representations in learning new words may be relevant, this is not the only conclusion that can be drawn from the experimental evidence. These significant relationships may well arise from the common speech processing involved in both activities.

Adams and Gathercole (1995) acknowledge the possibility of similar processing demands being responsible for the relationships found. They found that receptive vocabulary was more closely related to NWR than to digit span in 3 year-old children. They suggest that this might occur because "common to both NWR and vocabulary acquisition is the efficiency with which *novel* phonological forms can be processed.....it may be this overlap in processing demands that lies at the root of the highly specific link between NWR and vocabulary knowledge" (p. 411).

It can also be argued that any causal relationship between NWR and vocabulary development may be in the opposite direction to that claimed by Gathercole and Baddeley (1990a) and Gathercole et al. (1992). Snowling, Chiat and Hulme (1991) argue that children who have good existing vocabularies may be better at NWR than children who do not. For example, better morphological knowledge will enable a child to recognise elements of non-words, e.g. the affix 'ery' in 'thickery' and use this in production. This effect of existing lexical knowledge on NWR will be further discussed in Chapter 4.

Bowey (1996) evaluates the use of NWR as a measure of phonological memory, "NWR incorporates several components in addition to phonological memory" (p. 47). She comments on some aspects of the Gathercole and Baddeley (1990a) study of new word learning described above. Firstly, the children were taught to repeat the new names, and Bowey (1996) points out that this task is equivalent to NWR. As the children had already been divided into those who were good or poor at NWR, this would be expected to reflect in their performance on this first task of repeating the new names, and subsequently in learning the new names.

Bowey (1996) also argues that Gathercole and Baddeley's (1990a) hypothesis, that only phonological memory contributes to vocabulary development, can only stand if it accounts for further significant variation after other phonological processing skills have been accounted for. Bowey (1996) reports her own study of a large group of 5 year-old children. Phonological sensitivity (more usually termed phonological awareness) and phonological memory (digit span and NWR) were both significantly correlated with vocabulary development. Factor analyses showed that the

phonological memory tasks, phonological awareness tasks, and receptive vocabulary and grammar skills were all loaded onto a single factor, suggesting a single underlying language ability factor. Multiple regression analyses revealed that after effects of age, non-verbal skills and phonological awareness had been controlled for, digit span accounted for further significant variation in vocabulary development, but NWR did not. However, phonological awareness accounted for further significant variation in vocabulary after the effects of phonological memory had been controlled for. Bowey (1996) concludes that there is "no support for the notion of a specific link between phonological memory and receptive vocabulary in 5 year-old children.....findings are consistent with the latent phonological processing ability account" (p. 66). As NWR requires a high level of phonological processing skill, its relationship with vocabulary development is unsurprising.

Another contribution to this debate comes from Metsala (1999). Metsala found that neither NWR scores nor digit and word span scores accounted for any further significant unique variation in vocabulary knowledge, once variation due to age and phonological awareness skills had been entered into the equation. Metsala (1999) argues that NWR is related to vocabulary development because they are both correlates of a third variable, i.e. the underlying structure of lexical representations. "The robust relationship between vocabulary and NWR is not a function of common variance due to short-term memory, but rather reflects the underlying structure of lexical items" (p. 11).

Metsala (1999) argues that vocabulary development aids the shift from whole to segmented representations as restructuring of the lexicon takes place in development. This shift towards segmented representations allows

the development of phonological awareness skills. Phonological awareness skills and more accurately segmented representations, in turn, allow for more robust representation, and hence repetition, of non-words.

An alternative interpretation of Metsala's (1999) data may lie in the development of speech processing skills. More specifically, the clear relationship between NWR and phonological awareness that is found may be explained by common speech processing demands. For example, most of the phonological awareness tasks used in this study required the blending of onset and rhyme or of phonemes to make words and non-words. To do these tasks, children must first auditorally discriminate the spoken stimuli, then construct a motor programme of the blended stimuli and articulate the resulting motor programme. Stackhouse and Wells (1997) argue that even if the blended stimulus is a word, rather than a non-word, children may well take a bottom-up approach to this task. "Children will often produce a correct response out loud and then show surprise that what they have said is a real word" (p. 72), rather than recognising a known word from the segmented stimuli and accessing existing motor programmes. Auditory discrimination, motor programming and articulatory skills are all also implicated in successful NWR performance. It may be these skills that underlie the relationship between NWR and phonological awareness, rather than the structure of lexical representations. The case for common speech processing demands between NWR and vocabulary development has already been argued at the beginning of this section.

These studies show that although there appears to be strong and consistent correlations between NWR and vocabulary development, the nature of this relationship is unclear and may be complex rather than direct. Gathercole (1999) acknowledges that cognitive processes other than STM may

underlie the relationship between NWR and vocabulary development. She argues for the role of speech perception and phonological segmentation skills. Gathercole and Adams (1993) found that non-word and word repetition were both significantly correlated with vocabulary. Further analyses showed that this was not due to phonological memory variance, but rather to "a source of individual differences unique to word and non-word repetition" (p. 775), which implicates output processes. Consideration of the speech processing of tasks may help to untangle these relationships, and this will be a focus for this thesis. As a number of other factors may be responsible for associations between NWR and vocabulary development, then a relationship between vocabulary development and STM must also be demonstrated with the use of STM tasks other than NWR.

Vocabulary Development and Span

Bowey (1996) and Metsala (1999) included word and digit span measures in their analyses of which factors are important in vocabulary development. Bowey (1996) found that digit span was significantly correlated with receptive vocabulary in 5 year-old children. It also accounted for significant additional variation in vocabulary after controlling for the effects of age, non-verbal skills, phonological awareness and NWR. Metsala (1999) also found significant correlations between digit and word span and receptive vocabulary. In this study, STM did not account for significant additional variation in vocabulary after controlling for the effects of age and phonological awareness, in 4-5 year-old children, but did account for additional variation in 6 year-old children. There are some procedural differences between the studies of Bowey (1996) and Metsala (1999), particularly in terms of the phonological awareness tasks. It may be that differing levels of speech processing and cognitive demands on these tasks account for the difference in findings for the 5 year-old children.

The study by Avons et al. (1998) considered the relationship between word span and vocabulary development. Vocabulary was significantly correlated with span in 4-5 year-old and in 6 year-old children. Word span and a phonological awareness task predicted vocabulary one year later. Cross-lagged correlations indicated that the reverse relationships were not significant, vocabulary at age 5 years did not predict span or phonological awareness a year later. Avons et al. (1998) conclude that vocabulary development relies on phonological memory

A series of experiments was carried out by Gathercole, Service, Hitch, Adams and Martin (1999). Digit span was significantly correlated with performance on a word definitions task in 4 year-old children. Whilst this task may reflect vocabulary knowledge to some extent, performance will also be heavily influenced by more general expressive language skills. Digit span was also significantly correlated with a composite expressive and receptive vocabulary score for both 5 year-old children and 13 year-old children, when a single word measure was used.

However, Gathercole and Adams (1993) found that digit span was not significantly correlated with receptive vocabulary in 3 year-olds. Word span and digit span were not significantly correlated with receptive vocabulary in 4 and 5 year-old children (Gathercole & Adams, 1994). Whilst this is at odds with findings previously reported, it is possible that digit span performance is not representative of STM capacity in 3 year-old children, as digits may not be familiar to them. Adams and Gathercole (2000) used a measure of expressive vocabulary, of the number of different words used in samples of 4 year-old children's spontaneous language. This measure was significantly correlated with word span.

Avons et al.'s (1998) study showed different relationships for word span and for NWR and vocabulary. Receptive vocabulary was significantly correlated with word span at age 6 years but not with NWR. Word span at age 5 years predicted vocabulary scores a year later, but NWR did not. Span and NWR may not, therefore, be interchangeable tasks of phonological memory, in the context of language learning studies. The experiment reported in Chapter 6 will compare performance on NWR and STM for word lists in analysing relationships between phonological memory and language.

Role of the Phonological Loop in Vocabulary Learning

There is a body of opinion that one function of the phonological loop is to support language learning, and in particular vocabulary development (e.g. Gathercole & Baddeley, 1990a, Adams & Gathercole, 1995, Baddeley et al., 1998). Indeed Baddeley et al. (1998) argue that this is the primary purpose of the phonological loop, and that its use for recall in STM tasks is secondary to this. In a review of the literature, these authors find evidence of associations between NWR, word and digit span, vocabulary development and new word learning. These associations are found in children who are developing normally, in those who have specific language impairment, and in adults with learning disabilities or STM deficits. Baddeley et al. (1998) argue that "the function of the phonological loop is to provide temporary storage of unfamiliar phonological forms while more permanent memory representations are being constructed" (p. 159). These authors specify the phonological store as being the part of the phonological loop that is implicated in language learning. They present a model that acknowledges the role of existing lexical knowledge and of speech perceptual skills in STM performance and in vocabulary development.

Summary of Section1.3.i

There are clearly significant relationships between STM and vocabulary development. However, caution should be exercised in interpreting these relationships where NWR was the only STM task used. Findings where span measures have been used are not clear-cut. Despite strong claims for the phonological loop to play a causal role in vocabulary development, the nature of the relationship is not yet fully understood. In particular the speech processing demands of STM tasks and the contribution of speech processing skills to vocabulary development warrants more detailed consideration. These issues will be further considered in two experimental studies reported in Chapters 4 and 6. One reason for a lack of concord in the experimental findings is that different measures of STM and of language have been used and the children studied of different ages. It is possible that different mechanisms are important to different stages of vocabulary development. For example, Gathercole et al. (1999) acknowledge that "phonological memory constraints may become less important in learning new words in the later childhood years" (p. 71), with other factors, such as reading experience, becoming more influential.

1.3.ii STM and Grammatical Development

The relationship between STM and grammatical development has not yet been scrutinised so thoroughly as that of STM and vocabulary development. It is possible that vocabulary and grammar develop somewhat independently, with a slightly different cognitive profile underpinning successful performance in each aspect of language.

The relationship between phonological memory and spoken language in 3 year-old children was examined by Adams and Gathercole (1995). Spontaneous spoken language samples were examined for mean length of

utterance and grammatical complexity. Children who had poor combined phonological memory scores, based on measures of NWR and digit span, were compared with children who had high combined phonological memory scores. Mean length of utterance was significantly longer in the group of children with higher phonological memory scores. These children also scored significantly more highly on a measure of the complexity of their productive syntax. Analysis of the data suggested that the relationship found between NWR and productive syntax is mediated by speech rate. Adams and Gathercole (1995) argue that "articulatory abilities may limit the efficiency of the imitation process and hence the construction of the corpus of words and phrases that provide the basis for the development of syntactic knowledge" (p. 411). This suggests a role for speech output processing in language learning and in NWR performance. They agree with Speidel (1989) who argues that children's early articulatory skills influence the development of STM, which will in turn determine syntactic learning. Adams and Gathercole (1995) also hypothesise that phonological memory is important in children learning new syntactic constructions.

These measures of expressive language were also used in a study by Adams and Gathercole (2000). The mean length of utterance of 4 year-old children was found to be significantly correlated with NWR and with word span. The measure of productive syntax was also significantly correlated with NWR and with word span. A further study (Adams & Gathercole, 1996) found that a composite word and digit span measure and NWR scores were both significantly correlated with information and grammar scores on the Bus story task (Renfrew, 1991) in 3-4 year-old children. For this language measure the children retell a story, they have previously heard. Hierarchical multiple regression revealed that once variation due to vocabulary knowledge had been entered into the equation, span did not

account for any further significant variation in bus story scores. However, NWR scores did account for some further significant variation. Adams and Gathercole (1996) note the presence of a specific link between expressive language and NWR, and the absence of a link with span. They argue that this is evidence for the common influence of processing of phonological information in the absence of existing phonological representations in both NWR and language learning.

As has been discussed in the previous section, the use of the NWR task as a measure of phonological memory is open to interpretation, particularly in terms of the speech processing skills required, that are additional to STM. Adams and Gathercole (1996) acknowledge the role of phonological processing in spoken language development, and particularly the facility for phoneme segmentation and articulatory assembly, which will also be implicated in performance on NWR tasks.

Blake, Austin, Cannon, Lisus and Vaughan (1994) looked at the relationship between word span and imitation of increasingly complex sentences and mean length of utterance in the spontaneous language of 2- 5 year-old children. Word span was significantly correlated with sentence imitation for all the children and with mean length of utterance of the children aged under 3 ½ years, but not for the older children. Span accounted for further significant variation in sentence imitation and mean length of utterance after effects of age were accounted for. This suggested that word span was a good predictor of complexity of spontaneous language production for younger pre-school children. Blake et al. (1994) suggest that as children get older "increasing mastery of linguistic rules enables greater automaticity of speech programming, thereby obviating memory constraints, at least in spontaneous production" (p. 100). A second

experiment replicated these findings, with span proving to be a better predictor of mean length of utterance than chronological or mental age, in 3 year-old children. Blake et al. (1994) interpret these effects of span on performance as reflecting a capacity limitation model of STM (Just & Carpenter, 1992, cited in Blake et al., 1994). On this view limited capacity may constrain language storage and processing, which may be less taxed in spontaneous production, than in imitation of complex sentences. However, Blake et al. (1994) acknowledge that these correlational findings do not prove a causal link between STM and language skills.

Links between receptive grammar skills and STM in 5 year-old children have been examined by Bowey (1996). NWR and digit span were both significantly correlated with receptive grammar scores. Hierarchical multiple regression found that digit span explained significant independent variation in grammar after age, non-verbal skills and phonological awareness were controlled for, but NWR did not. This was confirmed in a similar finding by Ciccarelli (1996). In this study, Ciccarelli found that word span best predicted receptive grammar in 5 year-old children, whereas NWR did not. De Vincenzi, Ciccarelli and Rellini (1996) also found that word span showed a significant correlation with a measure of understanding 'who' and 'which' questions in 5 year-old children. NWR was not significantly correlated. Adams et al. (1999) reported that NWR, word span and digit span were all significantly correlated with a receptive language test, the revised Reynell Developmental Language Scales (Edwards, Fletcher, Garman, Hughes, Letts & Sinka, 1997).

However, some researchers do not find significant relationships between STM and grammatical development. In a group of 8 year-old children, STM performance, in recalling fixed-lists of 6 words, was not significantly

correlated with verbal comprehension as measured by the Token Test (DiSimoni, 1978) (Smith, Mann & Shankweiler, 1986)

Findings from most of these studies show clear indications of a relationship between STM and grammatical development. Several studies indicate that STM as measured by a span task is more strongly related to measures of receptive grammar than NWR performance is. As with the research into vocabulary development, this suggests that STM span tasks and NWR are not interchangeable measures of STM.

1.3.iii STM and Second Language Learning

A number of studies have examined the role of STM in second language learning. Whilst second language learning may not proceed in exactly the same way as first language learning, these studies may give some insight into language learning processes and a possible role for STM in these.

A longitudinal study showed that Finnish children's scores on NWR of English-sounding non-words at 9 years of age were significantly correlated with their English grades for both comprehension and production 2 to 3 years later (Service, 1992). Repetition of English sounding non-words and native language reading skills at age 8 years were significantly correlated with English language skills at age 9 years for another group of Finnish children (Dufva & Voeten, 1999). Using structural equation modelling, Dufva and Voeten found that NWR had less predictive power on English language skills than native language written word recognition skills. Dufva and Voeten (1999) conclude that native language skills could have affected both the learning of English and NWR skills, thus explaining the strong correlations between NWR and second language learning that has been found in this and previous studies

These studies of second language learning have used NWR as the measure of phonological STM, and so are open to the same arguments that have already been put forward for the relationship between NWR and vocabulary development. Dufva and Voeten's (1999) hypothesis that existing language skills may affect NWR and ability to learn a second language might also be applied to first language learning. It is possible that children with good early language skills may have more potential for further language development, than children who do not. Furthermore, accuracy of NWR might be affected by existing language skills, rather than influencing future language development.

Ellis and Sinclair (1996) explored second language learning in adults to examine the effects of encouraging or preventing repetition of the material being learned, to see if the sub-vocal rehearsal process was implicated. The participants who were encouraged to repeat the material learned significantly more about the grammar and phonology of the new language than those who had been prevented from rehearsing by articulatory suppression, or by remaining silent. Ellis and Sinclair (1996) conclude that WM, and particularly sub-vocal rehearsal, is heavily involved in language acquisition because it allows retention of sequences of language. However, this might also be considered to show the role of speech output skills in language learning, rather than functioning of the sub-vocal rehearsal process. Speech output skills have also been implicated in language learning by Adams and Gathercole (1995) (see Section 1.3.ii). Baddeley et al. (1998) have argued that it is the phonological store component of the phonological loop that is responsible for language learning, rather than the rehearsal process.

These studies indicate that whilst there may be a relationship between NWR skills and second language learning, this is not necessarily causal. One might expect the same mechanisms to apply to second language learning as they do to first language learning. Indeed, Dufva and Voeten (1999) demonstrate that this might be so, in that the children in their study with better first language skills, developed better second language skills than those who did not. Ellis and Sinclair (1996) have shown that speech output skills may play a part in language learning, but have not proved that this is mediated by the subvocal rehearsal process.

1.3.iv STM and Developmental Language Disorder

A number of studies have found children with language difficulties to have reduced STM (e.g. Kirchner & Klatzky, 1985, Gathercole & Baddeley, 1990b, Montgomery, 1995a, Gillam, Cowan & Day, 1995). These STM deficits seem to persist into adulthood (Isaki & Plante, 1997). These studies have focussed on a group of children with specific language impairment (SLI). These are children who have an otherwise unexplained difficulty with language acquisition, in that non-verbal cognitive skills are within normal limits for their age. The language difficulty cannot be wholly attributable to hearing impairment or to a lack of opportunity to learn language. These children form a heterogeneous group, and individually display a range of symptoms of difficulty.

The literature on STM and developmental speech and language difficulties will be reviewed in more detail in Chapter 7. However, any relationship between STM deficits and SLI is likely to be complex, and in part will reflect the nature of the relationship between STM capacity and language in normal development. The review, presented earlier in this section, suggests

that this is not yet clearly agreed. In disordered development there are at least three alternative possible relationships.

- STM deficits may be a causative factor in SLI
- STM deficits may be a consequence of SLI
- STM deficits and SLI may be correlates, co-occurring as symptoms of cognitive or processing difficulties.

Gathercole and Baddeley (1990b) argue that STM deficits, and particularly a reduced phonological loop capacity, result in language learning difficulties, and SLI. Van der Lely and Howard (1993) present evidence that children with SLI have a STM capacity that is the same as that of younger children at the same language level. The argument that follows this, is that children with SLI have STM capacities that are limited by their language level. It is possible that both SLI and STM deficits are both correlate symptoms of one or more underlying processing difficulties. A prime candidate for this would be speech processing. If the relationship between STM deficits and SLI can be more fully understood, this may allow the generation of further hypotheses about the relationship between STM capacity and language in normal development. The hypothesis that speech processing skills underlie STM functioning and language development in children with and without speech and / or language difficulties will be the main focus of this thesis.

1.4 CONCLUSION

This chapter has considered the WM model, in particular the phonological loop. Some aspects of speech processing skill seem to be important to the working of the phonological loop. There is reference to sub-vocal

rehearsal, and to the effects of concurrent speech and of word length and phonological similarity on STM performance.

It is clear, from the research findings reviewed, that there are relationships between STM and language development, although the nature of these relationships is unclear. An experimental study will be presented in Chapter 6 that will explore children's performance on STM tasks and on measures of language. Profiles of individual cases with speech and / or language difficulties will be considered Chapter 7.

Adams and Gathercole (2000) conclude that the association between phonological memory and spoken language development "may arise because both tasks share exactly the same set of cognitive processes" (p. 110). They suggest that "further consideration of the common processes of speech and memory might prove to be informative" (p. 100). This thesis will exam the role of speech processing skills in understanding the nature of the relationship between STM capacity and language in normal and atypical development. The functioning of the phonological loop, and a sub-vocal rehearsal process, would seem to require speech processing skills. Auditory discrimination and speech production skills and the development of lexical representations are likely to play a part in the development of spoken language. Difficulties in speech processing may also underlie both STM deficits and SLI. Research findings that pertain to the way in which speech processing skills may contribute to the development of STM and the functioning of the phonological loop will be fully explored in Chapter 2.

CHAPTER 2:
SHORT TERM MEMORY AND SPEECH PROCESSING SKILLS

2.1 INTRODUCTION

The research literature contains many findings that link speech processing skills with STM. These include significant relationships between STM and speech rate (Hulme et al., 1984), word identification time (Henry & Millar, 1991), word familiarity (Roodenrys, Hulme, Alban, Ellis & Brown, 1994), and mental processing speeds (Kail & Park, 1994). Much of this research has focussed on the phonological loop, and sub-vocal rehearsal mechanism, where the impact of speech output skills would seem to be most pertinent. More recently proposed models of STM also emphasise the role of speech input processing skills and existing lexical representations in recall (Henry & Millar, 1993, Gathercole & Martin, 1996).

Significant associations have been found linking STM and language development. These have been discussed in the previous chapter (Chapter 1). It was hypothesised that one explanation for these associations could be the influence of accuracy and efficiency of speech processing skills on both STM and language development. This chapter, therefore, aims to evaluate the role of speech processing skills in STM function and development.

Firstly, a developmental speech processing model will be presented. The role of speech processing in STM is outlined. Some task paradigms used in STM research are described, and the speech processing demands of such tasks are highlighted.

Secondly, experimental evidence for relationships between the development of STM and a range of speech processing skills is evaluated. The potential contribution of four aspects of processing to STM functioning is considered. These are:

- Speech output processing
- Speech input processing
- Lexical representations
- Mental processing speeds

2.2 A DEVELOPMENTAL SPEECH PROCESSING MODEL

A number of speech processing models have been used in psycholinguistic research, most notably Ellis and Young's (1988) model. This model accounts for the modules and connections that allow spoken and written word recognition and production to take place. For example, an auditory analysis system and auditory input lexicon are described that allow access to the semantic system for spoken word recognition.

However, such a model is based on research into adult speech and speech disorder. This study, therefore, focuses on a developmental model of speech processing (Stackhouse & Wells, 1997) (see Figure 2.1). The model distinguishes between:

i) auditory speech input processing, which involves perception, discrimination and recognition of the speech signal;

ii) storage of information about individual words in the form of lexical representations;

iii) speech output processing which allows phonological information to be retrieved from storage and articulated.

The model considers the processing of speech to be an interaction between 'bottom-up' processing, from the peripheral organs, i.e. ears and mouth, to lexical representations within the cognitive system, and 'top-down' processing, from lexical representations to the peripheral organs.

Figure 2.1: A developmental speech processing model, Stackhouse and Wells (1997)

Speech input processing

Bottom-up processing of speech heard occurs from the reception of a sound signal by the ear and hearing mechanism (peripheral auditory processing). Prelinguistic processing of the sound allows speech to be discriminated from non-speech signals. The next level of speech perception entails recognition of whether the speech heard belongs to a language familiar to

the child or not (phonological recognition). Off-line processing also allows for phonetic discrimination of speech from an unfamiliar language, or containing previously unheard phonemes, to be analysed.

Lexical representation

The speech signal can be compared to the child's existing phonological representations (lexical representations that contain sufficient phonological information to recognise words heard) to find a match. Access to phonological representations will also trigger semantic representations, containing information about the meaning of the words. This model separates input phonology (phonological representation) from output phonology (motor program). Thus, the motor program is considered to contain the more detailed specification of articulatory gestures that is required for pronunciation of a word. Speech output will require the accessing of the requisite motor programs.

Speech output processing

Children must be able to learn how to say new words, i.e. create new motor programs. Within this model, motor programming is the mechanism that allows for the creation of new motor programs. For new and familiar words the motor programs are then assembled into an utterance plan that incorporates all the necessary articulatory gestures (motor planning). This triggers movement within the vocal tract to result in an acoustic signal (motor execution).

'Bottom-up' and 'top-down' processing

Speech input processing requires some bottom-up processing of the sound signal. However, lexical representations will often facilitate recognition of the words heard, for example in the use of context, and this reflects the

influence of top-down processing. In speech output processing, the main direction of processing is top-down, from representation to motor execution, however, proprioceptive and kinaesthetic feedback loops through the output chain allow bottom-up processing to modify speech output.

2.2.i Speech Processing and STM

Some researchers argue for a close relationship between speech processing skills and STM. Following a review of research findings into the development of phonological skills, Snowling and Hulme (1994) argue that "we might consider STM mechanisms to be no more than a by-product of the mechanisms ..... that exist primarily for the perception and production of speech" (p. 23). Hulme et al., (1991) propose a model whereby verbal rehearsal, considered integral to STM in most current research, is seen as a by-product of speech production and perception processes. This view is partly supported by Gathercole and Martin (1996) who hypothesise that "the capacity for temporary storage of verbal material develops as a by-product of the speech input processing system" (p. 73).

The model proposed by Gathercole and Martin (1996) highlights the role of speech processing in recall. In contrast to the reliance on speech production processes required for sub-vocal rehearsal in the traditional WM model, Gathercole and Martin (1996) emphasise the role of input skills, and suggest that "there is no separate temporary memory system" (p. 77). Rather, they argue that the perception of the verbal material to be remembered triggers temporary activation of phonological representations, and that these representations are then used in recall. This model allows an explanation of lexicality effects found in STM task performance. These have included better recall for familiar words than for non-words (Hulme,

Maughan & Brown, 1991), for familiar words than for less familiar words (Hulme et al., 1994), and for more 'word-like' nonwords than less 'word-like' nonwords (Gathercole, Willis, Emslie & Baddeley, 1991). These findings will be discussed in more detail in Section 2.4.iii of this chapter, and in Chapter 4. This 'interactive' model (Gathercole & Martin, 1996) suggests that STM performance is reliant on the mechanisms and knowledge used in processing speech, with particular emphasis on speech input mechanisms, and 'top-down' processing.

Henry and Millar (1993) also use experimental findings of effects of word familiarity to argue for the role of long-term memory in developmental increases in STM span. These and other findings lead Henry and Millar (1993) to propose a model for the development of STM span that "has three main constituents : 1) phonological input storage which decays over time; 2) a speech output system which can be used for verbal recall or for active rehearsal of the material; and 3) long-term lexical memory as well as long-term memory for speech output procedures" (p. 278). This model (Henry & Millar, 1993) fits the philosophy of the current study in which the integrity of the child's whole speech processing system is considered to play a determining role in STM performance.

Hulme and Roodenrys (1995) suggest that "performance on a STM test will depend on many different psychological processes, most obviously attentional, perceptual and response mechanisms as well as storage mechanisms" (p. 375). The perceptual and response mechanisms of STM tests are often speech based. Thus, the contribution of speech processing to STM performance at input, storage and response stages is acknowledged. So, whilst STM capacity itself may be related to speech processing skill,

performance on STM tasks will also be affected by the speech processing demands of the task.

Different task paradigms have been used in research into, and assessment of, STM. These tasks often require elements of input and output speech processing skills and access to phonological and / or semantic representations. Recall tasks may involve participants in listening to spoken material and either repeating it or pointing to pictures that represent the items presented. The spoken material will consist of words, which may be very familiar or less familiar, or non-words. Spoken presentation will require input skills of speech perception, discrimination and recognition. If words the listener is familiar with are used, existing phonological and semantic representations are likely to be involved in processing the material and carrying out the task. The presentation of non-words will have different processing demands. The absence of existing representations will mean that lexical support is not available to support discrimination of the speech signal neither will established motor programs be available for the spoken response. Where spoken recall of the material presented is required, speech output processing skills will affect performance. Again, the use of words or non-words, and, hence, the availability of existing representations will also affect a listener's performance.

Other STM tasks may require the presentation of visual material with either spoken responses or picture pointing responses. Recognition of the visual material will access semantic representations and if material is to be verbally coded for rehearsal within the phonological loop, or for verbal recall, phonological representations will be accessed. Verbal recall will require all levels of speech output processing. Picture pointing responses will require semantic representations to be accessed from phonologically

coded material. The speech processing requirements of some STM task paradigms will be further examined in Chapters 4 and 5.

There is, therefore, scope for a reconsideration of verbal STM research methods and findings in the light of the importance given to speech processing skills by a number of influential researchers. The review that follows will focus on STM research within a developmental context.

2.3 SPEECH OUTPUT SKILLS IN STM

The aspect of speech output skills that have been most fully researched in relation to STM is speech rate. Within the psycholinguistic model (Stackhouse & Wells, 1997) speech rate measures could be viewed as reflecting motor execution skills, however, levels of motor planning and programming are also potentially involved.

2.3.i Speech Rate and STM

In children, research has suggested that developmental increases in memory span are a result of increases in speech rate (Hulme et al., 1984, Nicolson, 1981). For speech rate measures to be taken, children have usually been asked to repeat a word or sequence of words as quickly as they can. Measurement of the time taken has been undertaken with a stop-watch, or with the use of computer or oscilloscope technology in which a visual display of the speech signal allows time measurements to be taken. Hulme et al., (1984) found the number of words recalled in a STM task to have a very close linear relationship with speech rate in children aged 4, 7 and 11 years and in adults. The speech rate of older children was significantly faster than that of younger children, and the older children recalled significantly more items. It was the speed at which the words were

articulated that increased with age, rather than the shortening of spaces between the words. Several other subsequent studies have resulted in similar findings (Hulme & Tordoff, 1989, Hitch, Halliday, Dodd & Littler, 1989a, Hitch et al., 1989b, Hitch, Halliday & Littler, 1993). These findings have led to the hypothesis that developmental changes in speech rate might be responsible for the increases in STM that are found with age (Hulme & Tordoff, 1989, Hulme & Mackenzie, 1992). Within the WM model, speech rate is viewed as reflecting the speed of sub-vocal rehearsal within the phonological loop. Faster rehearsal will allow for longer lists to be maintained within the phonological store.

The reported relationship between speech rate and STM span is not necessarily causal. The studies cited above found correlations between speech rate and span. This does not prove that speech rate has a causal influence on STM. It is quite possible that both speech rate and STM span are independently determined by some other speech processing or cognitive factors, which increase with age.

Henry (1994) suggests that using group means for speech rate and memory span does not allow any relationship between the two in individual children to be examined. She found that speech rate was correlated with memory span for a measure of speech rate that was based on the repetition of pairs or triads of words, in children aged 5, 7 and 11 years. However, this relationship did not hold when the speech rate measure was for repetition of single words. When effects of age were controlled for, speech rate no longer correlated significantly with STM span. This suggests that speech rate could not be used to predict the memory span for individual children. This finding was in agreement with that of Standing & Curtis (1989, cited in Henry 1994) who also found that controlling for age resulted in the

correlation between articulation rate and memory span decreasing greatly. Henry (1994) reported that age was significantly correlated with measures of speech rate and with memory span. This correlation was stronger than that between speech rate and span, suggesting that developmental changes in span are more strongly related to some other factor or factors that develop with age, than with speech rate. Another study provides a similar finding. Kail and Park (1994) found that when speech rate was partialled out of the equation, age remained correlated with span.

The experimental design of matching a group of 5 year-old children to a group of 7 year-old children who demonstrated the same speech rate was used by Henry & Millar (1991). They found that the older children had significantly longer spans than younger children, and so differences in span could not be accounted for by speech rate. These results are not compatible with the hypothesis that increase in speech rate is a major factor in improvement in memory span as children get older. Henry & Millar (1991) argue that their approach of matching different age groups on speech rate provides a more stringent test of the causal hypotheses than correlational analyses. They conclude that although there are significant linear relationships between speech rate and span, these are not causal, and suggest the STM mechanism may be one of a fading storage system rather than active rehearsal.

The finding that some 5 year-olds could be matched with some 7 year-olds on speech rate (Henry & Millar, 1991) suggests that speech rate is not a very developmental sensitive measure. Williams and Stackhouse (2000) found that, in children under 5 years of age, rate was not as developmentally sensitive a measure as accuracy and consistency of word or syllable repetitions. Great variability in performance was found at each

age group examined and there was no significant difference between 3 and 5 year-olds on rate of repetition of 2 syllable words.

Other studies have failed to find a significant relationship between conventional speech rate measures and span in young children. Cowan (1992) did not find a significant correlation between speech rate during recall and memory span in 4 year-olds. In his study, as opposed to more traditional measures of speech rate in other studies, children were not asked to speak as quickly as they could, and the rate measure was taken during the recall process itself. Cowan, Keller, Hulme, Roodenrys, McDougal and Rack (1994) found that speech rate was correlated to span in 4 year-olds but in the opposite direction, to that which would be predicted by previous studies, i.e. slower speech rate was related to longer span. However, the usual, predicted relationship was found in 8 year-olds. Other studies have also failed to find a significant correlation between speech rates and digit or word span for 2, 4 and 5 year-old children (Gathercole & Adams, 1993, Gathercole, Adams & Hitch, 1994a, Gathercole et al., 1999). Gathercole and Adams (1994) found a significant correlation between speech rate and digit span, but not word span, at age 5 years.

There are, therefore, some contradictions in findings in the relationship between speech rate and span when only one age-group is studied. The relationship between speech rate and span seems to be a function of comparison across age-groups, as in Hulme et al.'s (1984) study. This relationship is, therefore, likely to be a result of developmental changes in cognitive systems, rather than arising from individual variation.

Gathercole and Adams (1993) argue that "it may be misleading and oversimplistic to view associations between articulation rate and memory scores as providing an unambiguous indicator of sub-vocal rehearsal" (p.

776). Rather, they suggest that associations between any tasks requiring a spoken output "may simply reflect the common influences of a child's accuracy in planning and executing a sequence of articulatory gestures" (p. 776). This is an argument for limitations in a young child's speech output processing skills affecting STM, where recall is spoken. It suggests that the output skills that influence STM are not confined to speech rate.

2.3 ii Sub-vocal Rehearsal

The speech rate / STM relationship is considered to reflect the functioning of the sub-vocal rehearsal mechanism. It is not yet clear whether increased speed of rehearsal does lead to developmental changes in STM. Some researchers argue that children below the age of about 7 years do not rehearse, and yet span improves during this time. The relationships that are reported between speech rate and span in younger children may arise because speech rate reflects the development of a range of speech processing skills that are becoming more efficient and more rapid as the child gets older, rather than merely reflecting speed of rehearsal.

A review of the evidence led Gathercole and Martin (1996) to agree with Flavell, Beach and Chinsky (1966, cited in Gathercole & Martin, 1996) that rehearsal does not take place in children until about 7 or 8 years of age. Henry and Millar (1993) arrived at a similar conclusion. Cowan, Cartwright, Winterowd, and Sherk (1987) found that when adults were prevented from rehearsing, their recall was similar to that of 5 year-old children, who were not prevented from rehearsing. This finding was interpreted to suggest that 5 year-old children do not rehearse

Henry (1991a) carried out a study in which children aged 5 – 9 years were trained to rehearse. Before training was carried out, observation was made

of children's use of vocalising or mouthing, which might have indicated rehearsal was taking place. This was observed in a third of children in the 9 year-old group, but was rare in 7 year-old children and non-existent in 5 year-old children, suggesting little vocal rehearsal was being carried out in the two younger groups. Results showed that rehearsal training significantly improved span performance, suggesting that rehearsal had not been used in STM tasks prior to the training. However training in the use of rehearsal did not improve the performance of the 5 year-old children to that of the older children, suggesting that continuing differences in span may not be due to increased use of rehearsal. Interfering in rehearsal by using concurrent speech did not result in any decrease in span in children aged 5 to 9 years.

Gathercole and Hitch (1993) argue that rehearsal in young children is qualitatively different from the sub-vocal articulation that seems to occur later. They suggest that in young children there may be "a reflex-like tendency to repeat words they have just heard" (p. 197) so that single items are repeated as they are presented, but not rehearsed in sequence. Key to Gathercole and Hitch's (1993) hypothesis is the idea of a 'phonological readout process' which "functions to map serially the phonological representations in the store component of the articulatory loop onto abstract articulatory gestures" (p. 198). Within this view faster speech rate is seen as affecting the recall process rather than reflecting increased rehearsal. Speech rate may be found to be related to span because it provides "a useful index of the speed at which a child can convert phonological representations into the abstract articulatory gestures necessary to guide articulatory output' (p. 199).

Jarrold, Baddeley, and Hewes (2000) examined STM in children with Down's Syndrome, who showed reduced STM spans. The children with Down's Syndrome showed similar speech rates to the control children who also had mild learning difficulties, and speech rate did not predict span in either group. Neither of the groups of children engaged in spontaneous rehearsal, and Jarrold et al. (2000) concluded that the STM deficit in children with Down's syndrome is not due to a lack of sub-vocal rehearsal. This is further evidence from a special population that speech rate and rehearsal may not be implicated in STM development in children.

If children under the age of about 8 years do not engage in sub-vocal rehearsal, then any relationship between speech rate and span is not likely to be the result of rehearsal. Developmental increases in span cannot be accounted for by increased efficiency of a rehearsal process.

2.3iii Spoken Recall

The functioning of the phonological loop has also been explored by comparing recall of short words and long words, the word length effect. This effect is robust, and a number of studies show that fewer long words can be recalled than short words (Hulme et al., 1984). The mechanism of the effect is similar to that argued for speech rate. Longer words take longer to rehearse, and so fewer can be retained, thus having the same effect as a slower speech rate.

Cowan, Day, Saults, Keller, Johnson and Flores (1992) suggest that word-length effects on span may occur at the stage of spoken recall, rather than at rehearsal, in adults. The increased time needed to produce a multi-syllabic item, delays output of the other items in the phonological store, which are then subject to decay. Cowan et al. (1994) argue that within the period of

recall, the time available for rehearsal is much less than is required to repeat the whole set of items. Pauses between words during recall were not affected by the length of the words being recalled, which they would have been if rehearsal was taking place.

Russell, Jarrold and Henry (1996) suggest that "non-verbal output can be said to give a purer measure of the word length effect because verbal output is contaminated by how long it takes a subject to say the words at recall" (p. 678). This paradigm was used by Henry (1991b), who found word-length effects on span when recall was spoken in 5 and 7 year-old children. However the word length effect was no longer present in the 5 year-old children when recall was via a probed, non-verbal pointing response. Henry (1991b) argues that "care must be taken to distinguish input and output processes in the development of children's STM" (p. 35) and that word length effects arise in the course of verbal recall, rather than storage and rehearsal. From a review of the literature, Henry and Millar (1993) also hypothesise that speech rate might be related to STM span because of its effect on verbal recall rather than on rehearsal. They cite Monsell (1987) who suggested that limitations in the output buffer are the result of the greater phonological complexity of longer words.

In locating the word length effect in spoken recall, rather than sub-vocal rehearsal, these findings could be used to justify hypotheses that speech rate might be related to span through the efficiency of spoken output.

2.3iv Motor Programs, Motor Planning and STM

This review has so far suggested that speech output skills, as measured by speech rate, is in some way implicated in the process of verbally recalling the items to be remembered in STM tasks. If speech rate is a critical

measure of STM performance, we should consider what aspect(s) of speech output processing are being tapped by speech rate measures. It may not be the motoric skill of rapid oral movement (motor execution) that allows speech rate to play an important role in predicting memory span. Rather, it may be the chain of output processing from access to motor programs, through motor planning, to motor execution that is implicated.

As reported previously in this chapter, Henry (1994) found that speech rate correlated with memory span when the measure of speech rate was based on the repetition of pairs or triads of words in children aged 5, 7 and 11 years. However, when the speech rate measure was for the repetition of a single word, this correlation was not significant. Henry (1994) suggests that the memory load of retaining two or three words in STM affects speech rate. She also considers that a speech output planning facility may be a factor in both speech rate and STM span. This facility would be taxed more fully when repeating a sequence of two or three words rather than a single word. If motor planning is influential in span performance, rather than motor execution, then repetition of pairs or triads is the measure that would be more closely linked with span, than repetition of a single word. Hulme et al. (1984) also found that speech rate for single words was more rapid than for groups of three words, and pinpoints greater demands in programming and executing motor commands for sequencing of three words rather than one.

Raine, Hulme, Chadderton and Bailey (1991) acknowledge that speech rate might be "an index of some other more central verbal process, which in turn determines the efficiency of STM performance" (p. 416). Raine et al.'s (1991) study investigated children, aged between 4 and 15 years, with a variety of speech disorders. As speech difficulty might mitigate against

successful performance in any task requiring verbal output, the stimuli for recall were presented as pictures and the response required selection of pictures. The performance of the children with speech disorders was compared with that of age-matched children who had no obvious speech impairment. Raine et al. (1991) found that the children with speech disorders had significantly slower speech than the group of children without speech disorder, and they also had significantly shorter STM span. They interpret these findings to show that STM span is linked with speech rate. The group of children showed a range of different speech disorders. It is not clear from Raine et al.'s (1991) study what level of speech output processing difficulty might be resulting in the children having a slow speech rate. Raine et al. (1991) observed less speech motor activity as the pictures were presented for recall, together with a reduced word length effect, for the children with speech disorders. This was interpreted to suggest that these children were less likely to use phonological coding to maintain the pictures in STM. The finding of a reduced span in the children with speech disorders might therefore be the result of use of a different, less efficient, strategy for recall from that of the children who did not have a speech disorder, rather than as a result of slower speech rates.

This difference in strategy for remembering is similar to that found by Johnston and Anderson (1998). Children with poor reading skills showed a reduced word length effect for picture presentation of items for recall, but not for verbal presentation. This suggested that this group of children had also not used a phonological coding for the picture material. In this instance, Johnston and Anderson (1998) observed that the children with poor reading skills often showed lip movement when pictures were presented and the children reported that they named the pictures to themselves. They suggest that the children with poor reading skills may

have verbally coded the items on presentation, but have relied on visual information during recall. The observations of lip movement and children's report were not systematically measured, and so the researchers could not be certain that the children with poor reading skills had not differed from children with normal reading skills on these measures. In any case, it is clear that a different strategy was being used for STM.

C. Henry (1990) also found significantly slower speech rates and significantly reduced digit span in 3-5 year-old speech disordered children as compared to non speech-disordered. Speech rate was significantly correlated with span in children with and without speech disorders. Raine et al. (1991) examined the findings from a sub-group of their children with speech disorders. The sub-group contained children who had dysarthria. This is a speech disorder of neurological origin that affects motor execution skills directly. Again the dysarthric children showed significantly shorter spans as compared to children without speech disorders. This is in contrast to Bishop and Robson's (1989) study which found that teenagers with anarthria or dysarthria performed in the same way as those with normal speech, in recalling word lists that were spoken or presented visually, with a picture-pointing response. These young people do not appear to have sufficient speech output skills for rehearsal. Bishop and Robson (1989) suggest that the rehearsal mechanism in STM must involve "abstract phonological representation, which, in normal individuals, would provide the input to a system that derives a speech motor program but does not itself contain an articulatory specification" (p. 139).

This finding was replicated by White, Craft, Hale and Park (1994), who also found no difference in span, despite significantly slower speech rates, in children with cerebral palsy, compared with children with no speech

difficulties. This was on a task with spoken presentation of stimuli and spoken recall. The speech difficulties of children with cerebral palsy are usually dysarthric in nature, i.e. a motor execution deficit. White et al. (1994) separate out overt and covert rehearsal, suggesting that central programming mechanisms are involved in both, with peripheral articulatory mechanisms implicated just in overt rehearsal. Their findings lead them to suggest that there are "different relationships between covert and overt rehearsal processes in some groups with impaired articulation" (p. 184). White et al. (1994) conclude that both groups were relying on covert rehearsal and that "normal speech rates are not necessary for development of covert rehearsal" (p. 184).

Gathercole and Hitch's (1993) hypothesis about the role of the phonological readout process may account for these findings from Bishop and Robson (1989), and White et al. (1994). For the anarthric and dysarthric young people the impairment is in peripheral articulation (motor execution) and not in the more abstract phonological system. The phonological representations of the items to be recalled were available for readout for the response, whether picture pointing or verbal.

Baddeley (1986) reports findings from a number of studies of unimpaired STM span in adults with acquired anarthria or dysarthria, and concludes that peripheral speech is not essential for normal mechanisms of STM. Rather, that the phonological loop and rehearsal processes of the WM model are "apparently relying on central speech control codes which appear to function in the absence of peripheral feedback" (p. 107). Within the context of a speech processing model, this suggests that more central aspects of speech output processing are implicated, such as access to motor programs, rather than motor execution skills.

Studies by Rochon, Caplan and Waters (1992) and Waters, Rochon and Caplan (1992) looked at STM in adults with acquired apraxia, a difficulty with motor programming and motor planning. These participants had reduced STM spans and slower speech rates when compared to adults without any speech difficulty. Analysis of a range of test and task results led Waters et al. (1992) to conclude that the rehearsal mechanisms involved in STM rely on speech planning processes that specify articulatory gestures rather than on the articulatory gestures themselves.

This evidence from children and adults with speech disorders links with more recent interpretations of the evidence from experimental studies (Gathercole & Hitch, 1993, Henry 1994) to suggest that motor execution skills are not influential in STM. Other aspects of speech processing may be implicated, for example access to motor programs and motor planning. Speech rate may be related to span because it is an observable measure that reflects these underlying, more central aspects of speech output processing.

2.4 SPEECH INPUT SKILLS IN STM

Speech perception has been found to be significantly correlated with STM span in young adults (Watson & Miller, 1993). Research with deaf children suggests that there are deficits in performance on STM tasks (Campbell & Wright, 1990). It is possible that the development of some aspect or aspects of speech input processing skills are implicated in changes in STM with age, and in STM task performance.

2.4.i Identification Time Hypotheses

One hypothesis in accounting for differences in span has centred on the influence of identification time, i.e. the speed with which stimuli are

recognised and identified. This measurement is usually made by recording the time taken to repeat words, from the beginning of the stimulus to the beginning of the response. Case, Kurland and Goldberg (1982) found a significant correlation between mean identification time and span in 3 and 6 year-old children. This correlation was still significant when age was controlled for, suggesting that STM span could be accounted for by individual differences in identification time.

Case et al. (1982) recognised that this measure of identification time included time spent in identifying words but also 'preparation time to respond'. From a speech processing perspective, in addition to the levels of speech input processing required to access the appropriate phonological representation, such a measure will include the initial levels of speech output processing of time needed to access a motor program, and possibly preliminary stages of motor planning. Hulme and Tordoff (1989) evaluated Case et al.'s (1982) hypothesis about item identification, in the light of findings of a relationship between speech rate and span. As Case et al.'s (1982) measure of item identification included speech-onset time as well as item recognition, Hulme and Tordoff (1989) suggested that the item identification component may not be the critical determinant of span. Rather the aspects of speech output involved up to the point of speech onset in the measure might have been the critical determinant.

Eleven year-old children were quicker to identify spoken and written words than 7 year-old children (Hitch et al., 1989b). However, neither identification time measure was significantly correlated with span. This was in accord with the findings of Cohen, Quinton and Winder (1985, cited in Henry & Millar, 1993) that 10 year-old children were faster than 6 and 8

year-olds to identify spoken letters, masked within a string of digits, but that this identification time measure did not correlate with span.

Hitch et al. (1993) found that item identification time was a poorer predictor of span than speech rate. Although item identification time was significantly correlated with span, multiple regression analyses revealed that once the variance in STM span that was due to speech rate had been removed, there was no further significant variation due to item identification time. However, when item identification time was entered into the analysis first, significant further variation due to speech rate was found. Hitch et al. (1993) concluded that there was no support for the role of identification time in the development of STM span.

As in their analysis of findings of significant relationships between speech rate and span, discussed in the previous section, Henry and Millar (1991) argued that the use of correlational evidence does not support a causal relationship between identification time and span. Henry and Millar found age-related increases in identification time for spoken words between 5 and 7 year-old children. However, when a group of 5 year-olds and a group of 7 year-olds were matched for identification time, STM span was still significantly better in the 7 year-old group. Henry and Millar (1991) suggested that identification time accounted for some but not all the variation in span and that the relationship between identification time and span does not reflect causation.

Following a review of the literature, Henry and Millar (1993) conclude that there is insufficient support for the hypothesis that identification time is responsible for developmental changes in span, but acknowledge that it may be "a subsidiary factor in span growth" (p. 247).

2.4ii Operational Efficiency Hypotheses

The work by Case et al. (1982) on item identification time was linked to the hypothesis that the processing space available for STM recall does not change with age, rather the processing of the material to be recalled becomes faster and more efficient. Within this model total processing space is viewed as consisting of storage space and operating space (for carrying out information processing). As the capacity required for operations, e.g. encoding and retrieval, decreases (with age and practice) so the amount of capacity available for storage increases.

Case et al. (1982) found that when adults identification time was equated to that of 6 year-old children by asking them to repeat taught non-words, rather than known words, then span for this material was also at the same level as the 6 year-olds. This finding was also replicated in using a counting task to measure operating speed. Case et al. (1982) conclude that "developmental changes in operational speed are highly correlated with developmental changes in span" and "when operational speed is controlled, there is no significant difference in measured span across widely different age groups" (p.. 403).

Other research with adult participants has shown that when speech input was degraded this had a detrimental effect on recall. STM performance was poorer when stimuli were presented against a white noise background rather than against no noise (Rabbitt 1968); when stimuli were presented in synthetic speech rather than natural speech (Luce Feustal & Pisoni, 1983); and when stimuli were presented in an unfamiliar rather than a familiar dialect (Mattingley, Studdert-Kennedy & Megan, 1983) (all cited in Brady, 1991). Brady (1991) uses this evidence to argue for the operational efficiency hypothesis in that when speech input processing is made more

difficult, as in the above experiments, more capacity is taken up in processing and less is available for storage and recall.

However, Towse and Hitch (1995, cited in Cowan, 1997) used evidence from experiments with counting tasks to argue that poorer STM performance on a more complex task was not due to a higher processing load reducing the capacity available for storage. Rather, the time taken to complete the task was critical. Towse and Hitch's findings highlight the role of decay or interference in recall that occurs across time. It may be that processing efficiency or ease of processing is one important factor and time taken to process is another.

Nation, Adams, Bowyer, Crane, and Snowling (1999) found children with poor reading comprehension who had reduced STM spans were not impaired on a spatial working memory task and so rejected the notion of general processing capacity limitations being responsible for poor STM performance.

The debate about operational efficiency highlights the possible influence of quicker and more efficient speech input processing on STM. This might improve with age. On this view, more accurate auditory discrimination skills and greater specification of phonological representations would allow faster recognition of words heard and free up resources for storage.

2.4iii Phonological Representations and STM

More recent work presented by Gathercole and Martin (1996) views STM development as a "byproduct of the speech input system" (p. 73). The interactive nature of speech processing is acknowledged, with bottom-up speech perception being supported by existing lexical knowledge through

top-down processing. In this model "processes of speech perception result in the temporary activation of phonological representations for incoming speech, and that these representations form the basis for performance in immediate memory tasks" (p. 77). If this is so, then speech input processing skills will be key, and any difficulties with speech perception would result in a reduced performance on a STM task. Stackhouse and Wells (1997) and Vance (1997) argue that speech perception skills will underlie the integrity of phonological representations. If this is so, then speech perception skills will also influence STM skills through the availability of accurate, well-specified phonological representations for temporary activation.

Gathercole and Martin (1996) present research findings of NWR performance in English - French bilingual children. The non-words reflected either the English or the French phonological system. The study showed a clear effect of language–specific knowledge on repetition of non-words for children who had been later learners of the second language. Gathercole and Martin (1996) interpret this to show that the speech perception system is attuned to the sound structures of the language a child is exposed to at an early age. This evidence fits the hypothesis within the Stackhouse and Wells (1997) speech processing model of a level of speech input processing of phonological recognition. This is the point at which the speech heard is recognised as belonging to a language familiar to the child or not. So STM research (Thorn & Gathercole, 1999) is linked with psycholinguistic theories of speech processing, and speech input skills are implicated in the STM task of NWR.

Effects of phonological neighbourhoods on STM task performance may reflect the involvement of phonological representations in recall. When NWR is used as the STM measure, children are better able to repeat non-

words that have been rated as being more wordlike, than non-words that have been rated as less wordlike (Gathercole et al., 1991). This issue will be discussed further in Chapter 4. Wordlikeness ratings have been found to be associated with the number of phonological neighbours that the non-words generate (Gathercole & Martin, 1996). This leads to an assumption that the more well-specified phonological representations a child has, the better they will perform on a NWR task. It also suggests top-down processing influences performance.

A complementary view is explored by Frankish (1996) in a review of relevant literature. In addition to the phonological recognition and access to phonological representations involved in STM (e.g. as described by Gathercole and Martin (1996) above), Frankish concludes that some STM representations may be based on purely acoustic features. Bottom-up processing of the sound signal, allows acoustic information to be registered in a more peripheral echoic memory. In this case, lexical representations are not accessed, and the material is stored in a relatively unanalysed form.

The role of speech input skills on STM capacity and performance has been less closely examined than the role of speech output. There is some evidence for an influence of speech perception and item identification on STM recall. Some theoretical perspectives have been outlined. However, this is an area of STM research that may benefit from further investigations. Item identification covers many different aspects of processing. Little experimental evidence has been collected on accuracy of speech perception skill and STM.

2.5 LEXICAL REPRESENTATIONS AND STM

Differences in children's recall of lists of words and lists of non-words were not completely accounted for by differences in speech rate for the two sets of lists (Roodenrys, Hulme, & Brown, 1993). Nation et al. (1999) found children's speech rate, for the items being recalled, did not entirely account for word length effects on word recall but did account for word length effects on non-word recall. They suggested that other factors were implicated in word recall, and that this might include semantic factors.

In the item identification time data, Case et al. (1982) found slower repetition of taught non-words than of words in adults. Henry and Millar (1991) also found that children identified more familiar words more quickly than less familiar words. These effects of familiarity on the speed with which spoken material is repeated may be the result of the integrity of lexical representations. In the research literature the terms long-term memory (Hulme et al., 1991, Roodenrys et al., 1993, Henry & Millar 1993) and knowledge (Cowan, 1997) are used. Both these terms seem to be referring to existing lexical representations.

Specificity and accuracy of lexical representations may be a possible source of the variation found in identification time for stimuli to be remembered and in speech rate for rehearsal and / or recall. One might expect that words that have been heard and said more frequently will be more quickly identified and articulated, in that phonological representations and motor programs are more fully specified and more efficiently accessed. Henry and Millar (1991) confirm this notion, finding that children took longer to identify and to articulate unfamiliar words than familiar words with the same number of syllables.

Hulme et al. (1991) compared span for words and for non-words. Adults recalled significantly more words than non-words that were matched for spoken duration, and this difference could not be accounted for by the speed with which the words and non-words could be articulated. Hulme et al. (1991) also found that adults could recall significantly more Italian words after they had learnt what they meant than before. Presumably, on first presentation the Italian words were non-words, whereas when meanings had been ascribed to the Italian words then lexical representations had been created. These two experiments show that recall for stimuli for which we have lexical representations is better than for stimuli for which we do not have lexical representations.

These findings are confirmed in studies with children. Span for non-word stimuli was shorter than for word stimuli in 3 – 6 year-old children (van der Lely & Howard, 1993). Better recall for words than non-words has also been found in 5 and 10 year-old children (Roodenrys et al., 1993). Again, this difference could not be accounted for by the difference in speech rate for the two sets of stimuli. Hulme, Roodenrys, Brown and Mercer (1995) found that recall for non-words improved when participants had an opportunity to repeat the non-words aloud first. Presumably this allowed rudimentary phonological representations and motor programs to be established and this aided recall. Roodenrys et al. (1993) argue that whilst speech rate is one determinant of STM span, availability of long-term memory representations, which increase and improve with age, is a second mechanism involved in the development of STM.

Some evidence that this might be a developmental factor comes from Roodenrys et al.'s (1993) study. The 10 year-old children showed a greater difference in recall of words than non-words, than the 6 year-old children.

The 10 year-old children would be likely to have a wider –range of well-established and well-specified lexical representations than the younger children. This difference between 10 year-old and 6 year-old children did not reach statistical significance, but suggested a developmental trend that may warrant further investigation.

Roodenrys et al. (1994) found effects of word familiarity on span performance in adults. High frequency words were better recalled than low frequency words. This finding was highly significant, and was confirmed by Hulme, Roodenrys, Schweickert, Brown, Martin and Stuart (1997). Walker and Hulme (1999) found concrete words were significantly more easily recalled than abstract words. Hulme et al. (1997) propose a model for the role of lexical representations in STM, whereby representations support a 'redintegration' process by which decaying material in the short-term store is refreshed. Phonological representations of more familiar words are viewed as being more accessible and / or better specified and so are more effective in this redintegrative process.

These effects of word familiarity on span were also reported in children by Henry and Millar (1991) and Henry (1994). Significantly longer lists of high- frequency words were recalled than for low-frequency words. Frick (1988, cited in Henry & Millar, 1993) suggests that as items are retrieved for recall they must be re-recognised from the information within the phonological store. This re-recognition is supported by lexical representations so that for more familiar words less phonological information is needed for re-recognition, whereas for non-words clear information about each phoneme is needed. This seems to be a similar process to that of 'redintegration' (Hulme et al., 1997) referred to above. Henry and Millar (1993) distinguish between two different aspects of word

familiarity: the familiarity of the item, in terms of having heard the word before and familiarity with procedures for retrieval, i.e. having had practice at retrieving it for speech output. They propose a model for STM development that includes a role for lexical representation as well as speech input and output systems.

Recent studies are beginning to highlight the role of existing lexical representations in STM performance and in the development of STM. Effects of range and quality of representations might also be reflected in input and output measures, such as item identification time and speech rate, that have been linked to STM. It is possible that relationships between identification time and speech rate and span arise because these measures rely on access to some aspect of lexical representation.

2.6 MENTAL PROCESSING SPEED AND STM

Some researchers have argued for the role of mental processing speeds in STM span development. Processing speed may account for STM development as information processing rates are known to change with age (Kail, 1988, Hale, 1990, Hale & Jansen, 1994, Kail & Salthouse, 1994, as cited in Cowan & Kail, 1996). Many studies in the field of STM research have found significant effects of various measures of speech rate, identification rate and access to lexical representations. Some of these have been referred to previously in this chapter.

Following a review of relevant research, Cowan and Kail (1996) suggested that the speech input and output processing skills and lexical representation knowledge that are involved in STM performance imply 'covert' mental processes. They argue for the role of a general factor – global speed of

processing – in the development of STM. Cowan and Kail (1996) view this as a global mechanism, not specific to speech processing or to STM, that affects speed of all processing and that changes with age. Cowan (1997) links this global speed of processing with maturation of brain tissue and the consequence of this on transmission of nerve impulses. Cowan (1997) suggests that faster processing may be critical in tasks such as STM where there may be a time limit on performance due to premises such as 'memory decay' or 'interference'.

Evidence from a study by Kail and Salthouse (1994, cited by Cowan & Kail, 1996) shows that controlling for a processing speed measure significantly reduced age effects in speeds of various other mental processes by 70-90%, in children and older adults. This suggested that there is "a substantial general component to the development of processing speed" (p. 44, Cowan & Kail, 1996). Kail and Salthouse (1994, cited in Cowan & Kail, 1996) also found that children's reaction times differed systematically from reaction times for young adults, showing a linear increase in reaction time which drops rapidly during childhood and more slowly during adolescence. Again, this suggested that some mechanism "that is not specific to particular tasks limits the speed with which children .... process information" (p. 45, Cowan & Kail, 1996).

Kail and Park (1994) proposed a model that illustrated possible relationships between age, processing speed, speech rate and STM span, (see Figure 2.2). Kail (1992) had evidence, from 9 year-old children and from adults, that age correlated both with processing speed and span, and that processing speed correlated with span. Calculation of path co-efficients suggested that i) age contributed to span, through processing speed; ii) age contributed to speech rate through processing speed; iii) age contributed

directly to speech rate independently of processing speed; iv) speech rate contributed directly to span.

Figure 2.2: Outline of model proposed by Kail and Park (1994)

Experiments with 7 to 14 year-old children also found evidence that age was significantly correlated with processing speed, speech rate and span, and that processing speed and speech rate were significantly correlated with span (Kail & Park, 1994). Path analyses confirmed most of the findings of Kail (1992), reported above. Speech rate was significantly linked directly to memory performance. However, all effects of processing speed were mediated by speech rate, there was no direct relationship between processing speed and span. Kail and Park (1994) argue that speech rate is an outcome of the increase in processing speed with age, but that age effects are not entirely explained by processing or articulation speeds. Kail and Park (1994) suggest that other variables may include the use of lexical representations and memory strategies.

This was further explored by Kail (1997), who looked at the relationships between STM and processing speed, speech rate and phonological skill, as

assessed by phonological awareness tasks. Multiple regression analyses revealed that speech rate and phonological skill were significantly related to span, but age and processing speed were not. Kail (1997) interprets this to suggest that speech rate and phonological skill contribute to the development of STM. Processing speed does not contribute directly to the development of span, but may do so indirectly as it was highly correlated with speech rate.

Cowan et al. (1994) suggested that as well as affecting item identification and response generation, a general processing speed factor, was also influential in a process of memory search rate that would have some effect on recall performance. This was measured as a function of the silent pauses between words during children's responses, as before items can be recalled, the STM representation is 'searched' to determine which words comes next in the list. Cowan (1992) cites work by Cavanagh (1972) that showed mental scanning speed was highly correlated with span. Cowan, Wood and Keller (1995, cited in Cowan 1996) found that memory search rate was not significantly correlated with speech rate, but that both measures were correlated with span. Cowan and Kail (1996) and Cowan (1996) suggest that this is another process involved in STM that is subject to the global processing speed factor. Cowan (1997) cites Keating et al. (1980) as suggesting that the memory search process is slower in young children, and so if memory search rate increases with age it may play a part in the development of STM.

Cowan (1999) further suggests that speech rate and retrieval / search rate (as measured by interword pauses in recall) contribute independently to span development and are influential at different stages of development. These two measures were not significantly correlated with each other in

children aged between 7 and 12 years. Speech rate was only significantly correlated with span at age 7-8 years, whilst retrieval rate was only significantly correlated with span at age 11-12 years. This study also matched span across age groups and found that, when this was done, there was no difference in retrieval rate between 7-8 and 9-10 year-olds, but there was still a difference in retrieval rate between 9-10 and 11-12 year-olds. Cowan (1999) argues that this suggests that processing speed is not directly implicated in a causal relationship between retrieval rate and span. There was no difference in speech rate between 7-8 and 9-10 year-olds or between 9-10 and 11-12 year-olds. Cowan (1999) concludes that these two aspects of processing develop independently of each other. This suggests that theories can not account for developmental changes in span with a general processing speed theory, but rather the speed of a number of separate processes may affect STM span. The retrieval rate measure used by Cowan (1999) may reflect, to some extent, access to long-term representations and the ideas about redintegration.

Chuah and Maybery (1999) looked at factors affecting verbal and visuo-spatial span in children aged 6-12 years. They found that most of the age related variance in span was shared by a processing speed measure and speech rate. Furthermore, all the influence of processing speed was age – related, whilst some of the variance due to speech rate was age independent. Chuah and Maybery (1999) concluded that the development of STM span was linked to increases in processing speeds and that there was no unique contribution of age to span other than that mediated by processing speed. This is broadly in agreement with Kail (1992) and Kail and Park (1994).

The possible importance of processing speed to STM may relate to the ideas of processing capacity formulated by Case et al. (1982), discussed in Section 2.4.ii. Within the operational efficiency model (Case et al. 1982) increased processing efficiency frees up space for storage, and therefore, aids recall. This efficiency may relate to processing speed, in that it seems reasonable to assume that more efficient processing will take place more quickly.

Smyth and Scholey (1996) found speech rate to be significantly related to digit span, but also to measures of visual and spatial memory. They proposed that speech rate acted as a general measure of processing speed, and that it was therefore related to other cognitive skills. On this view then, the robust findings of significant relationships between speech rate and span reflect the relationship between processing speed and span.

In evaluating these hypotheses, there is a need to be more specific about what is meant by mental or global processing speed. This is being measured in different ways in different studies, Some of the measures are directly related to STM processes, such as Cowan's (1999) retrieval or search rates. Processing measures that involve input or output speech processing have already been discussed, such as item identification and speech rate. Other measures seem to tap a wider range of processes, such as Kail and Park's (1994) number comparison or identical picture tasks where participants have to indicate whether two numbers are the same or not, or find a picture identical to the stimulus picture from an array. Cowan (1999) has suggested that STM is differentially affected by different speeds for different processes, rather than by a single global processing speed that determines rate of all processing. It also seems that different processes may be implicated in the development of STM at different ages (Cowan, 1999).

Different aspects of speech processing that seem to influence STM have been identified in the research, including recognition of words, access to phonological and semantic representations and motor programs, motor programming and speech output skills. It is not clear how far hypotheses, and evidence, concerning mental processing speeds and STM are confirming the role of speech processing rates in STM development and performance. It is also unclear how far speech processing rates are influenced by some other non-verbal cognitive processing speeds.

2.7 CONCLUSION

A developmental speech processing model has been described. Evidence has been presented to support the role of speech input and output processing skills and lexical representations in STM functioning and development. A view of STM is now emerging which is in accord with Snowling and Hulme (1994) that STM is integrated within the speech processing system. This is in line with the view that there is no separate phonological STM system, but rather STM tasks use phonological representations via the speech perception process (Gathercole and Martin 1996). On this view STM performance for material that is stored in a verbal form, is totally reliant on input and output speech processing skills and on lexical representations.

Speech rate has traditionally been viewed as key to the functioning of the phonological loop and to the development of STM. Studies of this have relied on correlational evidence. Where other experimental designs have been used, for example by Henry and Millar (1991) and Cowan (1999), in matching across age-groups, the predicted relationships have not been as clear. No single aspect of speech processing is clearly identified as playing

an exclusive, causal role in the development of span. Following a review of the issues in development of span, Gathercole (1999) concludes that "The substantial improvement in phonological storage capacities over the childhood years appears to have its origin in multiple component processes, many of which occur in parallel" (p. 414).

The existence of individual differences in speech input, output and representation may affect individual development of STM capacity and performance on STM tasks. It is also possible that deficits at any level of speech processing may mitigate against successful performance on STM tasks. Much of the evidence collected so far has focussed on the speed of the processes that may be involved, such as speech rate, identification rate, retrieval rate, general processing rate. Accuracy of speech processing has not been much studied. The focus in STM research has been more on the speed with which material can be identified or rehearsed, rather than the clarity with which temporary representations can be established. It is possible that STM is affected as much by the efficiency and integrity of the speech processing system, as it might be by the rate of processing.

If speech processing skills are linked to STM development and task performance, then it will be important to find appropriate measures of these skills. The measures can then be used in further experiments to examine the relationship between these processing skills and STM, and to examine how far speech processing skill contributes both to STM and to language development. Chapter 3 will present an experimental study, collecting data from young children performing a range of speech processing tasks were the measure is of accuracy, rather than rate, of performance.

CHAPTER 3:
EXPERIMENT 1: AUDITORY DISCRIMINATION AND SPEECH PRODUCTION TASK PERFORMANCE IN YOUNG CHILDREN

3.1 INTRODUCTION TO CHAPTER

In Chapters 1 and 2 discussion of some of the research findings in the field of STM revealed that speech processing skills may be implicated in the development of STM and also in STM task performance. It is possible that speech processing skills contribute to relationships between STM and language development. In order to test hypotheses about the development of STM and of the relationship with speech and language skills, it is first necessary to consider ways of measuring speech processing skills in young children.

In this chapter young children's performance on speech input and output processing tasks is considered. The developmental speech processing model (Stackhouse & Wells, 1997) that has already been presented in Chapter 2, will be used to provide a theoretical framework for the experiment. This model forms the basis of a psycholinguistic framework for the assessment of speech processing skills in children with speech and language difficulties. Within the context of this approach, analysis of children's performance on different task paradigms can provide insight into the level of speech processing deficits that might be the underlying cause of the child's difficulty (for a full discussion, see Stackhouse & Wells, 1997). Key to this is the analysis of the speech processing demands of different task paradigms, in terms of input processing, lexical

representations and output processing. It is expected that there will be differences in a child's performance on differing task paradigms.

The purpose of this chapter is two-fold.
Firstly, the speech processing and STM demands of a range of auditory discrimination and speech production tasks will be considered. Research findings of children's performance on such tasks will be discussed.
Secondly, an experimental report will present data from children aged 3-7 years old. Performance on a range of auditory discrimination and speech processing tasks will be analysed. The aims of the experiment are
i) to explore developmentally sensitive ways of assessing speech processing skills in children;
ii) to test hypotheses concerning differential performance across different presentations of auditory discrimination and speech production tasks.

3.2 INTRODUCTION TO EXPERIMENT

3.2.i Psycholinguistic Assessment of Speech Processing Skills

The psycholinguistic framework for the assessment of speech processing developed by Stackhouse and Wells (1997) has been introduced. Within this framework tasks used to assess auditory discrimination and speech production are analysed to identify the different levels of psycholinguistic processing that the task taps. Comparisons can then be made between performance on different tasks in order to analyse the speech processing profile of an individual child. For example, the comparison between task performance when words versus non-words are presented, allows evaluation of differences that may occur when the child can access lexical representations of the stimuli, rather than when he is processing material

for which he does not have any existing, matching representations. Comparison of tasks when visual versus spoken stimuli are presented allows evaluation of the state of a child's lexical representations. When stimuli are visual the child has to use his / her own representations to complete the task and top-down processing will be implicated. When stimuli are spoken to the child the processing may be bottom-up, the child can perform the task using the speech signal presented.

The psycholinguistic and STM properties of speech processing tasks that will be used in this study will be analysed, together with a discussion of relevant literature.

3.2.ii Auditory Discrimination Skills

Morgan-Barrie (1994) defines auditory discrimination as the "ability to perceive small differences in the properties and qualities of sounds that fall within the same type" (p. 24). When applied to the perception of speech this is usually taken to mean "the ability to differentiate between speech sounds as the minimal units that signal meaning differences" (p. 24).

Studies of auditory discrimination in babies and infants use behavioural responses (such as increased sucking, head-turning) to reliably reveal which sound differences are discriminable (e.g. Eimas, 1974, Eilers, Wilson & Moore, 1977). In older children it becomes more difficult to measure auditory discrimination skills and pre-school children often perform disappointingly on auditory discrimination tasks. Many other psychological processes are involved in the tasks that are most commonly used. Schissel (1980) identifies the following variables as being factors in performance: memory, attention, processing time; and there are other cognitive factors such as conceptual understanding that may also affect

performance. Kamil and Rudegair (1972) suggest that the "study of discrimination skills always involves inference. A task intervenes between behaviour and observation" (p. 1088). They found the performance of 5 and 6 year-old children on an ABX task and a same / different task (Auditory Discrimination Test, Wepman, 1958) improved significantly on repeated testing. Kamil and Rudegair (1972) suggest this was not the result of improved discrimination but of an "increased facility with the task, or to factors of attention, or to both" (p. 1090).

Auditory Discrimination Task Paradigms

Use of words and non-words in auditory discrimination tasks

Same / different and ABX auditory discrimination tasks may use word or non-word stimuli. Barton (1978, cited in Morgan 1984) found that "known vocabulary of items to be discriminated influenced perception to a significant degree". Significant effects of lexical familiarity on same/ different auditory discrimination have also been found by Atchison and Canter (1979). Normally developing children between 3 and 6 years of age were less able to discriminate non word pairs, such as 'fa/ba' (even after they had been trained to associate the non-words with toys and therefore to become somewhat familiar with them) than familiar word pairs, such a 'fox/box' (Velleman, 1988).

Differential performance between word and non-word tasks highlights possible differences arising from the influence of the direction of speech processing (Figures 3.1 & 3.2). In order to discriminate non-words bottom-up processing is implicated; information about the sounds contained in the stimuli must be derived from analysis of the speech signal. On the other hand, when words familiar to the child are used, top-down

processing can occur, involving the use of prior linguistic knowledge (i.e. semantic, phonological and orthographic). As soon as the child recognises the stimulus presented, he does not need to rely solely on his analysis of the speech signal to do the task. Mostly speech processing involves an interaction between bottom-up and top-down processing. Some children will perform better on auditory discrimination tasks in which words are presented, but the reverse might be true in other children whose long-term phonological representations are inaccurate and interfere with their judgement.

As well as differing speech processing requirements of the lexical and non-lexical stimuli, there may be differences in the STM demands. Bishop, Byers-Brown and Robson (1990) argue that "memory for meaningless phoneme sequences involves different processes from memory for real words" (p. 218) when lexical representations can be activated for phonological information to be retained. So, if words are used the child does not have to hold all the phonological information in a short-term store whilst he performs the comparison or judgement required, he can 'refresh' the stimuli by access to his existing phonological representations. This process, called 'redintegration' (Hulme et al., 1997), has been outlined previously in Chapter 2. For non-words, where no representations exist, this 'refreshing' of the content of the stimuli cannot take place.

Same / Different Task

For a same / different task the examiner either says the same word twice, e.g. 'chap / chap' or says two different words, e.g. 'tub / tug', (Wepman & Reynolds, 1987) and the child reports whether he has heard the same word or different words. His success with such a task will depend on his ability

to recognise and make judgements about the concepts of same and not the same, or different. Beving and Eblen (1973) found that 4 year-old children were significantly less able to judge whether non-word pairs were the same or different than they were able to accurately repeat the non-word pairs. Beving and Eblen (1973) concluded that these young children were unable to make the relevant cognitive judgements to do the task, although they could obviously discriminate the relevant sound differences sufficiently well to achieve correct repetitions of the non-word pairs. Task performance improved with age and 6 and 8 year-old children showed no significant difference between same/different judgements and repetition, suggesting that for older children judgement performance was a better reflection of discrimination skill. Johnston and Hook (1978, cited in de Montford Supple, 1991) agree that such tasks are requiring "the child to compare two words and, therefore, to reflect on sounds in words and make conscious judgements about them" (p. 30). They suggest that this 'conscious judgement' may depend on a range of other cognitive skills as much as on auditory discrimination ability.

For same / different tasks Locke (1980a) suggests there may be a mismatch between the child's responses and the tester's intentions. The child may discriminate "on the basis of a cue or set of cues the clinician does not have in mind, and may not even know about" (p. 433), for example using vowel fundamental frequency rather than voicing contrasts in /ta/ /da/ discrimination. Secondly, that the child's "failure to respond differentially does not necessarily mean that he detects no difference between the speech stimuli" (p. 433), but that he may not consider any difference he perceives to be large enough or of the right type to prompt a 'different' response.

Figure 3.1: Speech processing in auditory discrimination of non-words (after Stackhouse & Wells, 1997)

Figure 3.2: Speech processing in auditory discrimination of words (after Stackhouse & Wells, 1997)

Figure 3.3: Speech processing in auditory discrimination picture task (after Stackhouse & Wells, 1997)

Lower levels of input processing skills are utilised in performing this task, from peripheral auditory processing to phonological recognition. The child may access phonological representations if the stimuli presented are words, but does not need to – as the spoken stimuli can be compared using bottom-up processing skills. A discussion of the differences in discriminating words and non-words has already been presented earlier in this chapter, in Section 3.2.ii. Successful performance on same/different tasks requires some STM skills as the child retains the two stimuli for long enough to make the necessary comparison and judgement (Morgan-Barrie, 1994).

ABX Task

An alternative to the same / different paradigm is an ABX presentation. The child hears 2 different stimuli (AB), usually in association with 2 puppets, one of the stimuli is repeated (X) and the child is required to identify which puppet had spoken the repeated (X) stimuli. For example, this puppet says /brɪʃ/ this puppet says /brɪs/, who said /brɪʃ/.

Locke (1980b) advocates this task as a useful alternative to the same / different task because it bypasses some of the potential difficulties previously discussed in relation to same/different tasks. The same levels of speech input processing are implicated from peripheral auditory processing to phonological recognition. If this task uses non-word stimuli, then processing will be bottom-up, and no existing phonological representations for the stimuli will be available. There is a greater STM demand for the ABX than for the same / different task, with 3 stimuli to be compared rather than two.

Auditory Discrimination Picture Task

Locke (1980b) describes a useful procedure in which the child is presented with a picture portraying a single word that is then named either correctly or incorrectly by the examiner. For example, presenting a picture of a 'cat', the examiner may say /kæt/ or /tæt/ and the child responds whether the word spoken was correct or not for the given picture. This task requires the child to access his phonological representation of the word pictured (see Figure 3.3). Correct and incorrect presentations of the word must be compared to this stored knowledge, for the child to decide whether the word perceived matches the representation or not. All levels of input processing are implicated. STM requirements are relatively low, as the child only has one stimulus to consider at a time. However, the child may need to hold the non-word foil in temporary storage whilst a match with an existing phonological representation is attempted.

Differences in Performance across Tasks

Morgan-Barrie (1994) suggests that auditory discrimination tasks that use different paradigms are not measuring the same skill. It would be expected that different speech processing, conceptual and STM demands of tasks would lead to differences in performance. Experimental studies of performance on different tasks support this notion.

Bountress and Lauderberg (1981) found no significant correlation between the performance of a group of 5 year-old children on a same/different paradigm (Auditory Discrimination Test, Wepman, 1958) and a minimal pair picture pointing task (Goldman-Fristoe-Woodcock Test of Auditory Discrimination, Goldman, Fristoe & Woodcock, 1970). (In this picture pointing task, two pictures illustrating minimal pair words are presented

and the child asked to point to the picture of the word spoken by the tester. It uses the same levels of speech input processing as the auditory discrimination picture task described above.) Bountress and Lauderberg (1981) concluded that performance on these two tests was not comparable in measuring auditory discrimination. A further study (Bountress, 1984) compared performance between: i) the same / different task (as above) with a picture identification procedure, in which the child selected a pair of pictures from 3 pairs illustrated, e.g. cat-cat, cat-bat, bat-bat (Boston University Speech Sound Discrimination Test, Pronovost, 1974), in children aged 5-7 years; and ii) the two picture pointing- tasks (Goldman Fristoe & Woodcock TAD and Boston University SSDT), in children aged 5 years. Again no significant correlations were found between performances on the different tests. However, visual inspection of the data given suggests that a small number of individuals performed particularly poorly on the Boston University SSD, and this was not the case for the two tests that this was compared to. This might reflect some cognitive, attentional or STM difficulty with this test procedure that affected performance of some of the children and influenced the outcome of the correlational analysis. Performance on the same / different task (Auditory Discrimination Test, Wepman, 1958) was also found to be poorly correlated with performance on a minimal pair picture task (Auditory Discrimination and Attention Test, Morgan-Barry, 1989) in normally-developing children (Cracknell, 1987).

One potentially confusable variable in these experimental studies is that the different task paradigms compared used different sets of stimuli. The contrasts within the stimuli of one of the tests used may have been more difficult to perceive than those of the stimuli of the other test. One study

has compared the performance of a group of 4 year-old children on 4 different task paradigms, using the same or phonetically matched stimuli across the different tasks (Concanon, 1996). The tasks were:

a) a same / different task using non-words;
b) an ABX task using non-words;
c) an auditory lexical decision task in which children decided whether a spoken stimuli was a word or not; (speech processing demands on this task are the same as those of the auditory discrimination picture task described above);
d) an auditory discrimination picture task.

The children were most successful on the auditory discrimination picture task and least successful on the ABX task. Significant effects of task type were found, but there was no significant difference between the ABX and same/different task scores or between the auditory lexical decision and the auditory discrimination picture task scores. Thus, there were no significant differences between the pairs of tasks that had the same speech processing requirements. In this study the use of the same, or closely matched stimuli, allows variability in performance to be attributed to task differences, with less confounding variability from different stimuli sets.

Differential performance on two auditory discrimination tasks in young people with speech difficulties was reported by Bishop et al. (1990). A group of cerebral-palsied teenagers were given a non-word same/different task and an auditory discrimination picture task. Speech impaired participants, who had anarthria or dysarthria, performed significantly less well than age matched participants with normal speech on the same / different non-word task. They performed equally well on the auditory discrimination picture task. Bishop et al. (1990) hypothesised that this discrepancy in performance might arise as a result of differences in STM

demands of the two tasks. However, the speech impaired teenagers had shown the same memory span for a set of pictures as the non-speech impaired group (Bishop & Robson, 1989). Bishop et al. (1990) suggest that the speech impaired group may be having more difficulty in "retaining representation of all the phonemes of the two non-words" (p. 218) because non-words have no representation in long-term memory. Retention of such phonological information might be considered to be facilitated by subvocal rehearsal, which was clearly not possible in the anarthric group. However, the need for subvocal rehearsal for this task is questioned, given the findings, discussed in Chapter 2, of little evidence for such rehearsal in younger children.

Bird and Bishop (1992) also used a non-word same/different task and an auditory discrimination picture task, with a group of 5 – 6 year-old children with speech difficulties. There was no significant correlation between the group's performance on these two tasks. This led Bird and Bishop (1992) to conclude that "different auditory discrimination tests are not interchangeable, and task requirements can exert a major effect on performance" (p. 305).

From a psycholinguistic perspective the findings of differential task performance presented above are unsurprising. On this view different auditory discrimination tasks are considered to be tapping into different levels of speech processing.

Development Of Auditory Discrimination

Changes in auditory discrimination task performance have been shown with increasing age. School age children were significantly better at a

minimal pair picture pointing task than pre-school children (Morgan, 1984) and at a same / different task (Beving & Eblen, 1973). However the above discussion of the research findings and of conceptual demands of auditory discrimination task paradigms indicates that there may be significant measurement error from the other psychological processes involved, such as memory and other aspects of cognition. So, older children may perform better because they have more mature skills in other areas of cognitive functioning rather than that discrimination skills have improved.

3.2.ii Speech Production Skills

Children's speech production skills are usually assessed through obtaining a speech sample by asking a child to name pictures or to repeat words. This is then analysed phonologically by comparing the child's production with an accepted adult realisation of the same words. Factors that influence performance other than speech production skills are recognition of the pictures, accurate discrimination of the words to be repeated. Even very young children seem to be able to complete these tasks relatively easily.

Speech Production Task Paradigms

Naming

Children are often asked to name pictures in order to collect information about their speech production. Two commonly used assessments of speech production that use naming are the Edinburgh Articulation Test (Anthony, Bogle, Ingram & McIsaac, 1971) and the South Tyneside Assessment of Phonology (Amstrong & Ainley, 1988). The child must rely on his/her own phonological representation and motor program in order to name pictures. (The motor program is here considered to be the stored set of

instructions for the articulatory gestures required to achieve an acceptable pronunciation of the word (Stackhouse & Wells, 1997)). Once the motor program has been accessed, output processing levels of motor planning and motor execution then result in the word being spoken (see Figure 3.4). STM requirements of naming are minimal, as the child has the picture readily available, has access to a stored lexical representation of the word, and is only responding to one item at a time.

Word Repetition

Repeating words may tap different processes to a naming task. There are two ways in which a child may process words for repetition The child may use existing lexical representations to discriminate and recognise the word heard and then access the motor program for the spoken response. Other levels of output processing, i.e. motor planning and execution, are also involved (see Figure 3.5). However, the child may not use existing lexical representations, but rather use bottom-up input processing skills to perceive the spoken word presented for repetition and then utilise motor programming skills for the creation of a motor program for output (in a similar way to repeating a non-word, as discussed below).

A child may repeat some words more accurately than he names them, if his motor programs are inaccurate or incomplete. He may name pictures more accurately than he repeats the same words, as auditory discrimination skills are implicated in the repetition. So, if the child misperceives the word to be repeated then an incorrect response may be given. As with naming, STM requirements are minimal with only one stimulus to retain and repeat, and, if the child recognises the word, top-down processing will allow long-term storage to refresh STM, if required.

Figure 3.4: Speech processing in the naming task (after Stackhouse & Wells, 1997)

Figure 3.5: Speech processing in the word repetition task (after Stackhouse & Wells, 1997)

Figure 3.6: Speech processing in the non-word repetition task (after Stackhouse & Wells, 1997)

Non-word Repetition

In order to examine the child's speech production skills without interference from existing lexical representations, non-words can be presented for repetition. Within the framework of psycholinguistic assessment comparison of the repetition of words with repetition of non-words can aid the analysis of a child's speech processing profile. In order to compare performance more thoroughly, it may be useful to match the non-words closely with the words, so that phonological complexity and articulatory difficulty on the two sets of stimuli is equitable. A non-word may contain the same consonants as a word, e.g. /brɪʃ/ is matched to 'brush', or the consonants of a non-word may be matched with those of a word in terms of phonetic properties, e.g. /gləʊgəz/ is matched to 'crocus' (Ryder 1991). Within a psycholinguistic approach these two classes of stimuli are considered to have different processing requirements. When words are presented a child can use his lexical representations (semantic, phonological and orthographic) to help him to complete the task. When non-words are presented the child does not have an existing lexical representation, and, in particular, an existing motor program, to use to produce the non-word. However, there is evidence that children's performance will be affected by how similar a non-word is to a known word. (This issue of word-likeness effects on NWR will be further discussed in Chapter 4.)

To repeat a non-word, the child must be able to discriminate and perceive the sounds within the heard stimuli. This phonological information is, presumably, then retained in a temporary store (possibly the phonological loop component of WM). A new motor program must be created in order to articulate a word that has not been said before. Other levels of output

processing, motor planning and execution, are also involved (see Figure 3.6). However, within the psycholinguistic framework, this task is viewed as taxing motor programming skills in particular. There is some debate about the STM requirements of NWR. Some researchers (e.g. Gathercole and colleagues) would argue that NWR reflects STM skills. Indeed the use of the NWR task in STM research has already been discussed in Chapter 1. There will be further discussion of this task as a measure of STM and of speech processing in the following chapter, Chapter 4.

Children may repeat words more accurately than non-words if they use accurate, existing motor programs for output in word repetition. This difference in performance may be particularly marked if the child has a motor programming deficit. They may repeat non-words more accurately than words if existing motor programs are inaccurate, and satisfactory motor programming skills allow the creation of accurate, new motor programs for the non-words.

Differences in Performance across Tasks

There is evidence from studies involving children with speech and / or language difficulties of differential performance across these three speech production task paradigms: word repetition, non-word repetition and naming.

When investigating children with different symptoms of speech disorder, Willams and Chiat (1993) found different profiles of task performance. A group with phonological delay had similar error scores across the three measures of speech production. A group with phonological disorder showed significant differences in percentages of errors between tasks, with

the lowest percentage of errors made on the word repetition task and the highest percentage errors in the naming task.

Dodd, Leahy and Hambly (1989) also reported similar patterns of performance on naming and word repetition in children with phonological delay. Two groups of children with phonological disorders, who showed either inconsistent or consistent error patterns in their speech, were significantly more accurate in repeating words, than in naming pictures. These authors had considered that repetition would be the easier task as children did not need to access lexical representations, whilst picture naming required the accessing of lexical representations and the generation a plan for production (akin to the notion of the motor program). Bradford and Dodd (1994) found that the phonologically disordered children who made inconsistent errors were significantly poorer at a NWR task than children whose speech errors were consistent.

Thoonen, Maassen, Gabreels, Schreuder and De Swart (1997) found that two groups of 6-7 year-old children with dyspraxia and with normal speech made significantly more errors in non-word than word repetition. The dyspraxic children were also significantly poorer at both tasks than the control group. Gathercole and Adams (1993) found that performance on word and non-word repetition was significantly correlated in 2 to 3 year-old children with normally developing speech.

In addition to these group studies, the same range of tasks have also been used in single case studies to examine speech processing skills of children with speech difficulties. The individual subjects of some of these case studies have shown different profiles of performance. A case reported by

Bryan and Howard (1992) showed more accurate NWR than word repetition or naming. Stackhouse and Wells (1993) investigated a child who showed more accurate word repetition than naming. Whereas, Chiat and Hunt's (1993) case showed a very similar performance across the 3 speech production tasks. The authors of these studies use these different profiles of speech production performance to infer a particular speech processing deficit that underlies the child's speech disorder.

Development of Speech Production

The changes in speech production through the process of phonological development have been well-documented and normal developmental patterns in phonology have been identified (Grunwell, 1985). In the pre-school years, children will gradually modify their speech production and words become more adult-like, so that by the age of about 5 years children's speech production is mostly accurate. The development of adult-like speech production may be in part due to articulatory maturation, in that in early childhood, the requisite skills of range and co-ordination of oral movement are not yet fully developed (Stackhouse & Wells, 1997). Speech production may also mature as the phonological components of lexical representations are more accurately and clearly defined (Vihman, 1996).

3.3 RATIONALE FOR THIS EXPERIMENT

Later experiments within this thesis require the use of measures of speech processing skills. The existing literature suggests differential performance across different measures of auditory discrimination and speech production in children with normal and abnormal speech development. The

differences in speech processing demands, as analysed using the Stackhouse and Wells (1997) model, also suggest performance on tasks may differ. This experiment presents a range of different speech production and auditory discrimination tasks to groups of young children of different ages, who are all developing normally. This will enable the evaluation of performance on speech processing tasks to investigate differential performance, to outline a pattern of development, and to find developmentally sensitive tasks that reflect changes in the accuracy and efficiency of speech processing skills as children get older. It incorporates the use, where possible, of the same, or phonetically matched, stimuli to allow valid comparison between performances on different tasks.

3.3.i Predictions

One aim of this experiment is to find developmentally sensitive measures of speech processing. It is expected that:

i) performance on all tasks would improve with age.

Research findings suggest that there may be differences in performance across different task paradigms. The psycholinguistic framework approach would also predict differences in performance arising from the different levels of speech processing implicated in the task paradigms. It is, therefore, hypothesised that:

ii) performance across a range of auditory discrimination tasks would differ.

iii) performance across a range of speech production tasks would differ.

There may be cognitive skills or generic speech processing skills that are common to both input and output speech processing task performance. It is, therefore, predicted that:

iv) performance on speech production and auditory discrimination tasks would be correlated.

However, there may also be distinctive factors that affect input and output processing differentially. It is predicted that:

v) factor analysis of task performance will show that speech production tasks load together and auditory discrimination tasks load together.

3.4 METHOD

3.4.i Experimental Design

This experiment investigated the performance of groups of young children on a range of speech processing tasks. The between - subjects variable was age, and performance was compared for children within 5 different age-groups. Within subject variables were scores for each of 6 different experimental tasks of speech production or auditory discrimination.

3.4.ii Participants

One hundred 3 to 7 year-old children attending mainstream nurseries and primary schools were selected. Criteria for inclusion were:

i) no history of speech and language difficulties or of significant hearing loss

ii)considered by their teacher to be within the average range, with no evidence of any general or specific learning difficulty

iii)English as a first language

iv)no significant medical or neurological condition.

v)The Edinburgh Articulation Test (Anthony et al., 1971) was administered to all participants. All participants aged between 3 and 6 years (the age-limit of standardised data) obtained a standard score of above 85, putting their

speech development within normal limits. The tester is a qualified speech and language therapist and during the course of the experimental procedure screened for evidence of speech difficulties in the older children. This led to 2 potential participants being excluded from the study.

10 boys and 10 girls were included in each of 5 age bands, 3 years, 4 years, 5 years, 6 years and 7years (see Table 3.1). Children from at least 2 different schools were equally represented within each age-group.

Table 3.1: Subject characteristics of participants in Experiment 1

Age Group	N	Mean (s.d.) Age in years / months	Range in years/months
3 year-olds	20	3;7 (0.26)	3;1-3;11
4 year-olds	20	4;5 (0.27)	4;1-4;11
5 year-olds	20	5;6 (0.27)	5;1-5;11
6 year-olds	20	6;6 (0.29)	6;1-6;11
7 year-olds	20	7;5 (0.27)	7;1-7;11

The same / different task and the ABX task were only presented to the children aged 5 years and above, as a small pilot study had determined that most 3 and 4 year-old children were unable to understand how to perform the tasks reliably.

3.4.iii Task Materials and Procedures

Experimental Stimuli

Most of the experimental tasks used stimuli based on 60 core words. A list of 20 words were 1 syllable in length, a further 20 words were 2 syllables length, and 20 words were 3 or 4 syllables long.

Criteria for selecting stimuli words were:

i) expected to be within the vocabulary of 3 year-old children

ii) able to be illustrated pictorially

iii) word length as defined above

iv) within lists at each word length, a range of consonants and clusters were represented

v) within the 2 and 3 or 4 syllable word-lists, half the items were able to be manipulated to make metathetic changes, when sounds are transposed within the word, e.g. 'caterpillar' becomes 'capertillar'.

The stimuli were manipulated to make phonetically matched non-words for some tasks (see Table 3.2). Complete lists of experimental stimuli are included in Appendices 1 to 4.

Table 3.2: Examples of stimuli, at each word length, for experimental tasks.

Task	1 syllable	2 syllable	3-4 syllable
Naming /Word repetition	brush	sandwich	caterpillar
NWR	/bɹɪʃ/	/ˈsɪmwədʒ/	/ˈkɪtəpælə/
Auditory discrimination picture task (non-word foil)	/bɹʌs/	/ˈfæmwɪdʒ/	/ˈkæpətɪlə/
ABX	/bɹɪs - bɹɪʃ/	/ˈsɪmwədʒ- ˈfɪmwədʒ/	/ˈkɪtəpælə- ˈkɪpətælə/

Auditory Tasks

Auditory discrimination picture task

Fifty-eight colour photographs, a coloured drawing and a coloured square were prepared to illustrate each of the 60 core words. Each word from the

core list was paired with a matched non-word to create a 'mispronunciation' for each word. These non-word stimuli either i) differed by one phoneme with one distinctive feature difference, or ii) were the result of a metathetic change (see Table 3.2). The same stress pattern was maintained for the non-words as occurred within the matched words (see Appendix 2).

For half of the items, the picture was placed in front of the child and he heard one presentation of the word and one presentation of the derived non-word. For the other half of the pictures either the word or the non-word was presented twice. This prevented participants from assuming that only one word and one non-word would be presented for each picture, when their response to the second stimulus for each picture might be influenced by their response to the first. Responses to these extra presentations were not scored. A random order of presentation of stimuli was determined for each picture. Pre-recorded tapes were prepared with each stimulus spoken in the order of presentation, with a 2 second pause between stimuli, to allow time for the child's response.

This task was administered immediately after the naming procedure, which acted as a vocabulary check for this task. The child was introduced to a monkey soft toy and told "Monkey is going to try and say some words. Sometimes he says them right. Sometimes he says them wrong. Can you tell me if he is right or wrong". A picture was placed in front of the child who was asked "Monkey says X, is he right?". Corrective feedback was given for 3 practice items. The carrier phrase for the stimulus was phased out as soon as the child was responding appropriately so that only the stimulus word / non-word was being presented.

The test items were presented on the pre-recorded tapes to participants of 5 years and over, and in a live-voice condition for participants under 5 years of age, with the examiner's mouth covered to prevent lip-reading. The child's responses were noted.

Same / Different Task (after Bridgeman & Snowling, 1988)

Items were selected from the stimuli presented by Bridgeman and Snowling (1988). These consisted of pairs of words with a segment change, e.g. 'rate – race', a matching pair of words with a sequence change, e.g. 'raced – rates' and matching non-word pairs. The non-words were derived by changing the initial consonants of the word pairs to a phonetically similar consonant, e.g. */jeɪts - jeɪst/, /jeɪt - jeɪs/.* The word pairs selected for this task were those in which the sequence changes occurred in words with morphological suffixes e.g. 'rates – raced', rather than those pairs which were mixed in terms of presence and absence of morphological suffixes. There were 2 sets of stimuli, each containing 9 word pairs and 9 non-word pairs. Six of each set consisted of different word or non-word pairs, and 3 of each set consisted of same word or non-word pairs. (see Appendix 3).

Each child was presented with the pairs of non-words and words and required to say whether they were the same or different. The first items presented were the non-words pairs and then the word pairs. There were four practice pairs, for which corrective feed-back was given as required. The task items were presented one pair of words at a time with equal stress and neutral intonation on each word. An item was repeated once if the child failed to respond, or requested a repetition. The child's responses were noted.

ABX Task

The word - nonword pairs used in the auditory discrimination picture task were manipulated by changing the vowels to create a non-word pair (see Table 3.2). Each vowel was replaced by one of a similar length, i.e. short, long or diphthong. Stress patterns of the matched words were maintained for these non-words and marked. For half the items the first non-word to be presented was repeated, and for the other half of the items the second non-word to be presented was repeated (see Appendix 4). A random order was prepared for the items which were tape- recorded for presentation.

Two soft toys were placed in front of the child and practice items presented by pointing to one toy and saying "He says /səʊf/" and pointing to the second toy and saying "He says /təʊf/" and then asking "who said /səʊf/?". The child was encouraged to point to one of the toys. Corrective feedback was given as required for the practice items. During the practice items the cue phrases were phased out, so that just the non-word stimuli was spoken as each toy is pointed to, and then the child was asked "Who said X", finally omitting all the cue phrases so that the X stimuli were also presented as a single non-word. The test items were presented live-voice, with examiner's mouth covered. The children's responses were noted.

Speech Production Tasks

Naming

The pictures used in the auditory discrimination task, as described above were also used to collect the naming data (see Appendix 1). The participants were presented with each picture in turn and asked to name it. If a participant did not use the chosen stimulus word or failed to name the picture, then the tester used cues such as semantic, gap-fill, or first sound

cues to prompt him. If a phonological / first sound cue was used then, after a brief pause, the child was asked to say the word again and the second response recorded and scored. The child's responses were transcribed in phonetic script and tape recorded for later checking.

Word Repetition

The participants were asked to repeat the 60 core words (see Appendix 1). Three practice items were presented first with repetition and encouragement if the child failed to repeat the word. The test items were presented on pre-recorded tapes to subjects of 5 years and over, and in a live-voice condition for subjects under 5 years of age, with the examiner's mouth covered to prevent lip-reading. One live-voice repetition was given if the child failed to respond to an item or requested a repetition. Responses were transcribed in phonetic script and tape-recorded for later checking of transcription.

Non-word Repetition

A phonetically matched set of non-words were derived from the 60 core words by replacing each vowel with one of a similar length, i.e. short, long or dipthong. The consonants were maintained in the same sequence and the stress pattern mimicked that of the matched word (see Table 3.2 and Appendix 1). Sahlen, Wagner, Nettelbladt and Radeborg (1999b) advocate that words and non-words should be matched for stress patterns. In their study, children tended to omit unstressed syllables in prestressed positions in both word and non-word repetition. The non-words were listed in phonetic script and tape-recorded for presentation to the 5-7 year-olds.

The participants were told that the monkey soft toy was going to tell them some monkey words to say. It was emphasised that these would be silly, funny, made-up words that the child would not know. Stimuli were presented on pre-recorded tapes to subjects of 5 years and over, and in a live-voice condition for subjects under 5 years of age, with the examiner's mouth covered to prevent lip-reading. Three practice items were presented with repetition and encouragement if the child failed to repeat an item. The test items were presented singly with one live-voice repetition given if the child failed to respond or requested one. The child's responses were transcribed in phonetic script and tape-recorded for later checking.

Scoring of speech production tasks

Each response was analysed for realisation of the consonant sounds. To be counted as correct the consonants within the word or non-word were required to fit an accepted adult realisation, with the following variations allowed:

i) /ʊ/ for syllable final /l/ in e.g. hospital, multitude, crocodile;

ii) labio-dental 'r' /ʋ/ in e.g. brush (but scored incorrect if the phoneme articulated was /w/);

iii) interdental /s/ /s̪/ (but scored incorrect if the phoneme articulated was /θ/;

iv) /ʔ/ for plosives in syllable final position e.g. /tɹæʔtə / for 'tractor'; /eleʔtɹɪsəti/ for 'electricity.

v) 'pyjamas' with an unaspirated /p/.

vi) /tʃɹ / for /tɹ/ in e.g. train, tractor

vii) /s/ or /z/ for the alveolar fricative in 'electricity'

viii) /ɛəpleɪn / for 'aeroplane'

ix) 'hairdressers' or 'hairdresser' both accepted.

Any responses in which consonants deviated from accepted adult realisations were scored as incorrect, including words in which consonants had been added or omitted by the child.

Local accent is a variable to be considered in determining an adult realisation. The responses of the 7 year-old children from the sample on naming and real-word repetition were used to establish an appropriate pattern. For example, as the majority of 7 year-old children produced the phoneme /θ/ in words, then the common dialectal variation of /f/ used for /θ/ was scored as an error.

3.4.iv Experimental Procedure

The participants were tested in their school situation in a room or area away from other groups of children. There was background noise present in some settings, although this was minimised as far as possible. Early trials of the experimental tasks had suggested that children under the age of 5 years did not fully understand the procedure for the auditory discrimination same / different and ABX tasks. These tasks were not, therefore, presented to 3 and 4 year-old children.

Order of Presentation

The 60 core words were divided into 2 lists. List A contained all 1 syllable word or non-words and 10 of the 2 syllable word or non-words; List B contained 10 of the 2 syllable words or non-words and all 3 and 4 syllable words or non-words. Testing took place over two separate sessions, with the experimental tasks in the following order:

	Session 1	Session 2
NWR	List A	List B
Word repetition	List B	List A
Naming	List A	List B
Auditory discrimination picture task	List A	List B
ABX	List A	List B
Same/different task	All	

The ABX task was presented before the naming task to half the subjects. The order of presentation adopted prevented the child from hearing or saying a word before hearing the matched non-words, or from hearing a word before being required to spontaneously access it in naming. This decreased the likelihood of lexicalisation and ensured that the child used his own pronunciation in the naming task. On the administration of the tasks at session 2 the number of training items were reduced, at the examiner's discretion, if the child clearly remembered the procedure. The Edinburgh Articulation Test was administered at the end of one of the sessions.

3.5 RESULTS

3.5.i Auditory Discrimination Tasks

Means and standard deviations were calculated for number of items correct for each age group on each auditory discrimination task (see Table 3.3). As there were only two possible responses for each of these auditory discrimination tasks, there was a 50% chance of participants getting the correct answer for each item. Binomial tests were, therefore, carried out for

each task. For the auditory discrimination picture task, a raw score of 70 correct would be significantly above the chance level ($p<.05$). For the same / different task, a raw score of 24 correct would be significantly above the chance level ($p<.05$). For the ABX task, a raw score of 37 correct would be significantly above the chance level ($p<.05$). The mean scores are substantially above these levels, indicating that task performance was above the chance level.

Table 3.3: Mean (s.d.) number of items correct for each age group on auditory discrimination tasks.

Age Group	N	Aud. discrimination picture task No of items = 120	Same/different No of items = 36	Non-word ABX No of items = 60
3 years	17	99.9 (14.94)		
4 years	18	108.5 (10.29)		
5 years	20	111.5 (4.1)	29.80 (4.81)	40.25 (9.16)
6 years	20	113.5 (4.78)	33.00 (4.83)	45.65 (7.86)
7 years	20	114.7 (3.17)	35.25 (0.79)	52.30 (4.65)

Comparisons between age groups

Auditory discrimination picture task

Visual inspection of the means suggest that there are ceiling effects on this data, and the data was not normally distributed. A non-parametric test for independent samples was, therefore, selected. A series of Mann-Whitney tests were carried out to compare performance between consecutive age-groups. There were no significant differences between the performance of 3 and 4 ($U = 96$, $p = .059$), 4 and 5 ($U = 169$, $p = .747$), 5 and 6 ($U = 131$, $p = .061$), and 6 and 7 year-olds ($U = 178.5$, $p = .558$). However, there were significant differences in scores between 3 and 5 year-olds ($U = 85.5$, p=

.01) and 5 and 7 year-olds (U = 106, p= .01), but not between 4 and 6 year-olds (U = 127.5, p= .123).

Same / different task

Visual inspection of the means suggest that there are ceiling effects on the data, and the data was not normally distributed. Again Mann-Whitney tests were used to analyse the data and showed a significant difference between 5 and 6 year-old performance (U = 99.5, p = .006), and the difference in performance between 6 and 7 year-olds approached significance (U = 132, p = .051).

ABX task

Data for all age groups on the ABX task was found to be normally distributed and showed homogeneity of variance. Therefore, assumptions for ANOVA analysis were upheld. A One way ANOVA showed that performance on the ABX task showed a significant effect of age ($F_{(2,57)}$= 13.07, p < .001). Post Hoc tests using Bonferroni Multiple Comparisons showed no significant difference in performance between 5 and 6 year-olds (Mean Difference = 5.4, p = .078). There were significant differences in performance between 5 and 7 year-olds (Mean Difference = 12.05, p < .001) and between 6 and 7 year-olds (Mean Difference = 6.65, p = .02).

These analyses reveal effects of age on performance on each of the auditory discrimination tasks. Older children are scoring more highly than younger children, although scores between consecutive age groups are not always significantly different. There are ceiling effects on task performance in the older children for two of the auditory discrimination tasks.

Comparisons across tasks

Table 3.4: Mean (s.d.) percentage of items correct by 5-7 year-olds

	Aud. discrimination picture task	**Same/ different**	**ABX**
5 year-olds	92.92 (3.41)	82.78 (13.36)	67.08 (15.26)
6 year-olds	94.54 (3.99)	91.67 (13.43)	76.08 (13.10)
7 year-olds	95.54 (2.64)	97.92 (2.18)	87.17 (7.74)

In order to compare performance across the 3 experimental measures of auditory discrimination, the percentage of items correct for each task was calculated for the 5-7 year-old children (see Table 3.4).

Table 3.5: ANOVA table of Age X Task for percentage scores on auditory discrimination tasks by 5 and 6 year-olds.

Source of variation	**SS**	**DF**	**MS**	**F**	**Sig of F**
Error	9493.31	38	249.82		
Age	1269.31	1	1269.31	5.08	.030
Error	5534.81	76	72.83		
Task type	10364.71	2	5182.35	71.16	<.001
Age X Task	357.224	2	178.61	2.453	.093

As previously reported, there are possible ceiling effects on performance on the auditory discrimination picture task and the same / different task. However, for the data from the 5 and 6 year-old children, distribution and homogeneity of variance were considered and assumptions upheld. A mixed 2 (Age - between subjects) by 3 (Task - within subjects) ANOVA was used to analyse the data (see Table 3.5). The results showed main

effects of Age ($F_{(1,38)} = 5.08$, $p = .03$), and of Task ($F = 71.16$, $p < .001$). The Age by Task interaction was not significant ($F_{(2,76)} = 2.453$, $p = .093$).

The main effect of age shows that the 6 year-old children are scoring at a significantly higher level than the 5 year-old children. Post Hoc paired sample t tests were used to explore the main effect of task. Using the Bonneferroni Correction for multiple comparisons, the probability level for this series of t tests was calculated to be significant at $p<.02$. Percentage scores on the auditory discrimination picture task were significantly better than on the same / different task ($t_{(39)} = 3.486$, $p = .001$) and on the ABX task ($t_{(39)} = 11.385$, $p < .001$). Percentage scores on the same / different task were significantly better than on the ABX task ($t_{(39)} = 7.759$, $p < .001$).
In analysing the data from the 7 year-old children, a non-parametric related samples test, the Wilcoxon test, was used in order to allow for ceiling effects. Percentage scores for the same / different task were significantly better than for the auditory discrimination picture task ($Z = 2.877$, $p=.004$) and for the ABX task ($Z = 3.885$, $p < .001$). Percentage scores for the auditory discrimination picture task were significantly better than for the ABX task ($Z = 3.722$, $p < .001$).

For the 5 and 6 year-old children percentage scores are highest on the auditory discrimination picture task and lowest on the ABX task. However, for 7 year-old children percentage scores are highest on the same / different task and lowest on the ABX task.

Correlations between tasks

The ceiling effects identified in this data, may affect the correlational analysis, however, this should result in a more conservative estimate of

correlation. Visual inspection of the scattergrams for the variables did not reveal curvilinearity or the presence of any outliers. As previous analyses had revealed significant effects of age on performance on all 3 tasks, a partial correlation was carried out, controlling for effects of age. The correlational matrix (see Table 3.6) shows that all auditory discrimination measures are significantly correlated with each other at the .01 probability level. Performance on the 3 auditory discrimination tasks is closely related, a child who scores highly on one task will tend to also score highly on the other two tasks.

Table 3.6: Pearson's partial correlations, age controlled for, in 5-7 year-olds auditory discrimination performance.

	Aud. discrimination picture task	**Same / different**	**ABX**
Aud. discrimination picture task	1.00	.559**	.674**
Same/ different		1.00	.467**
ABX			1.00

** Significant at the level $p < .01$

Lexicality effects on same / different task

The scores on the same / different task were calculated to show the number of word pairs correctly identified and the number of non-word pairs correctly identified. Means and standard deviations were calculated (see Table 3.7). As ceiling effects were clearly present in the 6 and 7 year-old groups, the lexicality effect was explored using the Wilcoxon non-parametric related samples test. There was no significant effect of word type ($Z = 1.114$, $p = .265$). The children were just as accurate in judging

whether non-word pairs are the same or different as they were when judging word pairs.

Table 3.7: Mean (s.d.) number of items correct for same / different task.

Age Group (N=20)	Same/ different words No of items = 18	Same/different non-words No of items = 18
5 years	15.20 (2.57)	14.60 (2.46)
6 years	16.35 (2.66)	16.65 (2.48)
7 years	17.65 (0.75)	17.6 (0.50)

3.5.ii Speech Production Tasks

Means and standard deviations were calculated for number of items correct for each age group on each speech production task (see Table 3.8). As the 3 speech production tasks used the same or phonologically matched stimuli, they were treated as levels of a single factor for analysis.

Table 3.8: Mean (s.d.) number of items correct for each age group on speech production tasks.

Age group N = 20	Naming	Word Repetition	NWR
		Number of items = 60	
3 years (*N= 17)	34.05 (8.68)	40.00* (9.85)	38.76* (7.79)
4 years	42.50 (5.61)	47.50 (5.77)	43.15 (4.67)
5 years	51.10 (5.67)	52.25 (4.31	46.25 (3.55)
6 year	51.35 (4.22)	53.95 (3.99)	47.75 (4.22)
7 year	54.20 (3.93)	53.30 (3.01)	48.85 (4.66)

Normal distribution and homogeneity of variance were considered and data for all 5 age-groups did not show homogeneity of variance. Inspection of the means and standard deviations suggested that this was due to the greater variability in the performance of the 3 year-old group, as opposed to the other age groups. The data was, therefore analysed in two sections. The performance of the 3 year-old children on the 3 tasks was compared with that of the 4 year-old children. Then data from the 4-7 year-old children was considered.

Three and Four Year-old Children

For the 3 and 4 year-old age groups data was normally distributed and showed homogeneity of variance. Therefore, assumptions were upheld.

A mixed 2 (Age - between subjects) by 3 (Task - within subjects) ANOVA was used to analyse the data (see Table 3.9). The results showed significant effects of Age ($F_{(1,34)}$ = 8.035, p=.008), and of Task ($F_{(2,68)}$= 22.583, p <.001). The Age by Task interaction was not significant ($F_{(2,68)}$= 2.623, p=.080).

Table 3.9: ANOVA table of Age X Task for speech production in 3 and 4 year-olds.

Source of variation	SS	DF	MS	F	Sig of F
Error	4749.329	34	139.686		
Age	1122.337	1	1122.337	8.035	.008
Error	665.908	68	9.793		
Task type	442.295	2	221.295	22.583	<.001
Age X Task	51.369	2	25.685	2.623	.080

The main effect of Task was examined using paired sample 't' tests. Using the Bonneferroni Correction for multiple comparisons, the probability level for this series of t tests was calculated to be significant at $p<.02$. Word repetition scores were significantly better than scores on NWR ($t_{(37)} = 3.519$, $p <.001$) and on the naming task ($t_{(37)} = 7.812$, $p <.001$) and NWR scores were significantly better than naming scores ($t_{(37)} =2.864$, $p = .007$). The interaction between Age and Task was not significant, however a probability level of $p = .08$ suggests that there may be a trend. Visual inspection of means for task types at different ages suggests that, between 3 and 4 years of age, there is greater improvement in naming and word repetition performance, than there is in NWR (see Figure 3.7).

Figure 3.7: Mean performance on speech production tasks, by age-group.

Four to Seven year-old children

Data from the 4, 5, 6 and 7 year-old children also satisfied the assumptions of normality and homogeneity of variance. A mixed 4 (Age - between subjects) by 3 (Task - within subjects) ANOVA was used to analyse the data (see Table 3.10). The results showed main effects of Age ($F_{(3,76)}$ =

16.595, p <.001), and of Task ($F_{(2,152)}$ = 92.103, p <.001). The Age by Task interaction was also significant ($F_{(6,152)}$ = 5.387, p <.001). This interaction is illustrated in Figure 3.7.

Table 3.10: ANOVA table of Age X Task for speech production in 4-7 year-olds.

Source of variation	SS	DF	MS	F	Sig of F
Error	3608.283	76	47.777		
Age	2363.679	3	787.898	16.595	<.001
Error	1098.767	152	7.229		
Task type	1331.585	2	665.787	92.103	<.001
Age X Task	233.658	6	38.943	5.387	<.001

Simple Effects of Age

Analysis of simple effects of Age for each Task was carried out using Scheffe post-hoc multiple comparisons. For the *naming* task 4 year-old children performed significantly less well than 5 year-olds (Mean Difference 8.60, p<.001) but there was no significant difference in performance between the 5, 6 and 7 year-olds. For the *word repetition* task 4 year-olds performed significantly less well than 5 year-olds (Mean Difference 4.75, p < .05), there were no significant differences in performance between 5, 6 and 7 year-olds. For the *NWR* task there was no significant difference between 4 year-olds and 5 year-olds. However, 4 year-olds performed significantly less well than 6 and 7 year-olds (Mean Difference 4.60, p < .05 and 5.70, p<.001); there was no significant difference in performance between 5, 6 and 7 year-olds.

Simple Effects of Task

Paired sample t tests allowed simple effects of task at each age to be explored. Using the Bonneferroni Correction for multiple comparisons, the probability level for this series of t tests was calculated to be significant at $p < .004$. In *4 year-old children* word repetition scores were significantly greater than naming ($t_{(19)} = 6.345$, $p < .001$) and NWR scores ($t_{(19)} = 3.876$, $p < .001$). Naming task performance was not significantly different from NWR performance ($t_{(19)} = .638$, $p = .531$). In *5 year-old children* word repetition performance was not significantly different from naming performance ($t_{(19)} = 1.373$, $p = .186$), but was significantly better than NWR performance ($t_{(19)} = 8.816$, $p < .001$). Naming task performance was significantly better than NWR performance ($t_{(19)} = 4.712$, $p < .001$). *6 year-old children* were significantly more accurate in word repetition than in naming ($t_{(19)} = 4.022$, $p = .001$) and in NWR ($t_{(19)} = 8.521$, $p < .001$). They were significantly more accurate in naming than in NWR ($t_{(19)} = 4.313$, $p < .001$). In *7 year-old children* word repetition scores were not significantly different from naming ($t_{(19)} = 2.191$, $p = .041$), but were significantly higher than NWR scores($t_{(19)} = 7.248$, $p < .001$), and naming task performance was significantly better than NWR performance ($t_{(19)} = 5.825$, $p < .001$).

Older children perform more accurately on all three speech production tasks than younger children. The children score more highly on word repetition than on naming (except in the oldest age-group), and NWR scores tend to be the lowest scores (except in the younger children). The significant interaction between Age and Task shows that the relationship between performance on the different tasks changes with age. At the age of 4 years, scores on naming were not significantly different from NWR

scores. As children get older, performance on naming improves significantly more than on NWR, so that by the age of 7 years, naming scores become more closely related to word repetition scores (see Figure 3.7).

Word length effects

In order to clarify effects of length of stimuli on accuracy of speech production, the required analyses were carried out separately. Visual inspection of the mean number of items correct for each age group, for the lists of differing word lengths, suggested that children's speech production was less accurate for the longer words on each of the 3 tasks (see Table 3.11). There is a greater difference in performance between 2 syllable and 3-4 syllable stimuli, than between 1 syllable and 2 syllable stimuli.

The data for all of the 5 age-groups did not show homogeneity of variance. Repeated measures Task X Word Length Analyses of Variance were, therefore, carried out for each age group in turn.

For *3 year-old* children, data was normally distributed and showed homogeneity of variance. There was a significant effect of Task ($F_{(2,30)}$ = 10.52, $p < .001$) and of Length ($F_{(2,30)}$ = 50.55, $p < .001$) and the interaction between Task and Length approached significance ($F_{(4,10)}$ = 2.47, $p = .054$).

For *4 year-old* children, data was normally distributed and showed homogeneity of variance. There was a significant effect of Task ($F_{(2,38)}$ = 15.19, $p < .001$) and of Length ($F_{(2,38)}$ = 13.33, $p < .001$), but the interaction between Task and Length was not significant ($F_{(4,76)}$ = 1.36, $p = .255$).

Table3.11: Mean (s.d.) number of items correct for each word length, on speech production tasks

Age group	Naming			Word Repetition			Non-word Repetition		
	1 syllable	2 syllable	3-4 syll.	1 syllable	2 syllable	3-4 syll	1 syllable	2 syllable	3-4 syll
	No of items = 20			No of items = 20			No of items = 20		
3 years	14.38	11.81	8.8	15.06	13.19	11.75	14.19	12.94	11.50
N=16	(2.83)	(3.90)	(3.61)	(2.91)	(3.15)	(4.71)	(2.79)	(3.42)	(3.01)
4 years	15.30	14.85	12.35	16.30	16.30	14.90	15.20	14.65	13.30
N=20	(1.81)	(1.90)	(3.23)	(2.11)	(2.11)	(3.31)	(1.94)	(2.08)	(2.45)
5 years	17.55	17.70	15.85	17.80	17.50	16.95	15.25	16.30	14.7
N=20	(1.79)	(1.30)	(3.18)	(1.20)	(1.76)	(2.58)	(1.68)	(1.34)	(2.41)
6 years	18.35	17.50	15.50	18.65	17.75	17.55	16.70	16.05	15.00
N=20	(1.31)	(1.50)	(3.07)	(1.35)	(1.68)	(1.99)	(1.22)	(1.23)	(2.70)
7 years	18.8	18.45	16.95	18.30	18.30	18.7	16.05	16.95	15.80
N=20	(1.20)	(1.28)	(2.33)	(0.80)	(1.59)	(1.17)	(1.88)	(1.90)	(2.33)
Total	16.30	17.04	15.38	15.41	16.35	15.08	13.04	15.28	13.74
N=96	(2.59)	(2.31)	(2.09)	(3.38)	(2.74)	(2.43)	(4.39)	(3.97)	(2.89)

For *5 year-old* children, data was normally distributed and showed homogeneity of variance. There was a significant effect of Task ($F_{(2,38)}$ = 27.36, p <.001) and of Length ($F_{(2,38)}$ = 9.58, p <.001), but the interaction between Task and Length was not significant ($F_{(4,76)}$ = 1.85, p = .128).

For *6 year-old* children, data was normally distributed and showed homogeneity of variance. There was a significant effect of Task ($F_{(2,38)}$ = 35.37, p <.001) and of Length ($F_{(2,38)}$ = 13.05, p <.001), and the interaction between Task and Length was significant ($F_{(4,76)}$ = 3.15, p <.019).

For *7 year-old* children, data was normally distributed but did not show homogeneity of variance. Keppel (1991) (p. 98) suggests that provided F_{max} is 9 or greater[1], then the results of ANOVA will not be compromised. For the data for 7 year old children F_{max} =8.49. There was a significant effect of Task ($F_{(2,38)}$ = 37.62, p < .001) and of Length ($F_{(2,38)}$ = 5.04, p =.011) and a significant interaction between Task and Length ($F_{(4,76)}$ = 6.00, p <.001).

Visual inspection of the means (Table 3.11) showed that less accurate performance in producing the 3 – 4 syllable words was responsible for the significant effects of length at each age. For the 3 year-old children, the interaction between Task and Length approached significance. The graph of this interaction (see Figure 3.8) suggests that word length affects accuracy of naming more than word and non-word repetition.

[1] F_{max} is the value derived by dividing the largest within-group variance by the smallest within-group variance.

Figure 3.8: 3 year-old children's mean performance on speech production tasks, by stimulus length.

For 6 year-old children, the interaction between Task and Length was significant. The graph of the interaction (see Figure 3.9) suggests a different pattern to that found in the 3 year-olds. The simple effects of length were explored using a series of paired sample t tests. Using the Bonneferroni Correction for multiple comparisons, the probability level for this series of t tests was calculated to be significant at $p < .008$. For *2 syllable words* word repetition task performance was not significantly different from naming ($t_{(19)} = .754$, $p = .460$), but was significantly better than NWR performance ($t_{(19)} = 4.587$, $p < .001$). Naming was significantly more accurate than NWR ($t_{(19)} = 3.960$, $p = .001$). However, for *3 syllable words* word repetition task performance was significantly better than naming ($t_{(19)} = 3.342$, $p = .003$) and NWR performance ($t_{(19)} = 6.168$, $p < .001$) but there was no significant difference between NWR and naming accuracy ($t_{(19)} = .768$, $p = .452$).

Figure 3.9: 6 year-old children's mean performance on speech production tasks, by stimulus length.

The interaction between Task and Length was also significant for 7 year-old children (see Figure 3,10). The simple effects of length were explored using a series of paired sample t tests. Using the Bonneferroni Correction for multiple comparisons, the probability level for this series of t tests was calculated to be significant at $p < .008$. For *2 syllable words* word repetition performance was not significantly different from naming ($t_{(19)} = .471$, $p = .643$), but was significantly better than NWR performance ($t_{(19)} = 3.048$, $p = .007$). Naming was significantly more accurate than NWR ($t_{(19)} = 3.422$, $p = .003$). For *3 syllable words* word repetition task performance was significantly better than naming ($t_{(19)} = 4.742$, $p < .001$) and NWR performance ($t_{(19)} = 5.253$, $p < .001$) but there was no significant difference between NWR and naming accuracy ($t_{(19)} = 2.025$, $p = .057$).

Figure 3.10: 7 year-old children's mean performance on speech production tasks, by stimulus length.

There is a clear effect of word length across all three tasks, with children being significantly less accurate in their production of longer words. For the youngest children, word length is having the greatest effect on naming, which is poorer than either repetition task (see Figure 3.8). In the 6 and 7 year-old children, the picture is more complex. For 2 syllable stimuli performance on naming is comparable with word repetition, and NWR is significantly less accurate. However, for 3-4 syllable words there is a marked deterioration in naming accuracy, such that naming becomes comparable with NWR, with word repetition being significantly more accurate (see Figures 3.9 & 3.10).

Correlations between tasks

The data from the speech production tasks is normally distributed. Visual inspection of the scattergrams for the variables did not reveal curvilinearity or the presence of any outliers. As previous analyses had revealed

significant effects of age on performance on all 3 tasks, partial correlations were carried out, controlling for effects of age. The correlational matrix (see Table 3.12) shows that all speech production measures are strongly and significantly correlated with each other at the level of p<.01.

Table 3.12: Pearson's partial correlations, age controlled for, in children's speech production tasks.

	Naming	**Word repetition**	**NWR**
Naming	1.00	.805 **	.653**
Word repetition		1.00	.690**
NWR			1.00

** Significant at the level p < .01

This suggests that there is some commonality in performance on different speech production tasks, children's accuracy of production will be reflected in a similar way in the different task paradigms.

3.5.iii Comparison between Speech Production and Auditory Discrimination Performance

Correlations between auditory discrimination and speech production performance

The 3 and 4 year-old children only completed the auditory discrimination picture task and 3 speech production tasks. For this group the data is normally distributed. Visual inspection of the scattergrams for the variables did not reveal curvilinearity or the presence of any outliers. As previous analyses had revealed significant effects of age on performance, a

partial correlational analysis was used, controlling for effects of age. Auditory discrimination picture task scores were significantly correlated with scores on each of the 3 speech production measures (see Table 3.13).

Table 3.13: Pearson's partial correlations, controlling for age, for auditory discrimination picture task and speech production tasks in 3 and 4 year-olds.

	Naming	**Word Repetition**	**NWR**
Aud. discrimination picture task	.595**	.479**	.680**

** Significant at the level $p < .01$

The 5 to 7 year-old children completed all auditory discrimination tasks. However, due to ceiling effects on some of these, only data from the 5 and 6 year-old children was normally distributed. Visual inspection of the scattergrams for the variables did not reveal curvilinearity or the presence of any outliers. Partial correlations, controlling for age, were carried out for 5 and 6 year-old children (see Table 3.14). Scores on the 3 auditory discrimination were significantly correlated with scores on naming and NWR, but not significantly correlated with scores on word repetition.

The data shows that in the 3 and 4 year-old children auditory discrimination skills are significantly correlated with the range of speech production measures. For the 5 and 6 year-old children the correlations between auditory discrimination skills and speech production are less strong, and for auditory discrimination and word repetition, the correlation is not significant.

Table 3.14: Pearson's partial correlations, controlling for age, for auditory discrimination and speech production tasks, in 5 and 6 year-olds.

	Aud. Discrimination Picture Task	**Same / different**	**ABX**
Naming	.350*	.389*	.346*
Word repetition	.229	.297	.297
NWR	.524**	.381*	.380*

* Significant at the level $p < .05$, ** Significant at the level $p < .01$

Factor analysis

Exploratory factor analysis of data for all speech production and auditory discrimination tasks was carried out to identify any factors that might be underlying performance across this range of tasks. Principal components analysis (with Varimax rotation) revealed two components with Eigenvalues of more than 1. The auditory discrimination tasks – auditory discrimination picture task, same / different and ABX, were grouped into Component 1, and accounted for 60% of variance. The speech production tasks - naming, word repetition and NWR, were grouped into Component 2 and accounted for an additional 19% of the variance (see Table 3.15).

Thus, two separate factors are identified that might underlie performance on speech processing tasks. One factor appears to be common to tasks of auditory discrimination skills and the other common to tasks of speech production.

Table 3.15: Rotated component matrix showing the three auditory discrimination measures load onto component 1 and the three speech production measures load onto component 2.

	Component 1	Component 2
ABX	.847	.310
Aud. discrimination picture task	.890	.152
Same / different	.813	.260
Naming	.211	.874
NWR	.375	.742
Word Repetition	.173	.919

3.6 DISCUSSION

The predictions made for this data, will now be considered in turn.

3.6.i Effects of Age on Task Performance

There appear to be developmental changes in performance, with this stimulus set, on this range of speech production and auditory discrimination tasks.

Auditory Discrimination Tasks

The auditory discrimination picture task was not sensitive to developmental changes between consecutive age-groups. However, significant differences were found between the scores of 3 year-olds and 5 year-olds and 5 year-olds and 7 year-olds. The lack of significant differences on performance may be, in part, due to the ceiling effects present in this data. For the same/different task there was a significant

difference between 5 and 6 year-olds performance but not between 6 and 7 year-olds, possibly due to ceiling effects on the 7 year-old data. In contrast, the nonword ABX task showed no significant difference between 5 and 6 year-olds but a significant difference between 6 and 7 year-olds. There was a greater variability in the performance of the 5 and 6 year-old groups on the ABX task, as shown in the large standard deviations. There may have been some children who did not have the conceptual understanding and / or STM capacity to do this task, and who were, therefore, individually performing at a chance level.

The issue of conceptual understanding required for many auditory discrimination tasks have been discussed in Section 3.2.ii. The conceptual demands may adversely affect the performance of younger children on these tasks. Attention control is likely to be another confounding variable. It was noticeable when collecting the data that attention control was quite variable, particularly for the auditory discrimination tasks. This would probably have more effect when more than one stimulus has to be attended to, for example in the ABX task.

Each of the auditory discrimination tasks was, therefore, developmentally sensitive for some of the age range tested. However, it is clear that at different ages, different tasks may be more representative of auditory discrimination skills, as there may be ceiling effects on some tasks and confounding variables affecting performance on others.

Speech Production Tasks

Analysis of the data shows significant effects of age on accuracy of speech production. For the three speech production tasks post-hoc testing of age

effects suggests that whilst there is significant improvement in performance between 3 and 4 year-olds and 4 and 5 year-olds for the tasks, there is no significant improvement in performance between the 6 and 7 year-olds. This may reflect stages of phonological development, in that by the age of 6 years most children have acquired an adult system. Performance on the speech production tasks may reflect this mature system. However, although scores on naming and word repetition were approaching ceiling levels in the 7 year-old children, this was not so for NWR. This may suggest that factors other than phonological development affect performance on NWR. The Stackhouse and Wells (1997) model would propose motor programming skills as affecting performance. Gathercole et al.'s (1994b) hypotheses about NWR imply that PSTM capacity will affect performance. These three speech production tasks are therefore developmentally sensitive for younger children, i.e. those aged 6 years and below.

3.6.ii Differences in performance on auditory discrimination tasks.

Performance on each auditory discrimination task was significantly correlated with performance on each other task. This is in contrast to studies by Bountress and Lauderberg (1981), Bountress (1984) and Cracknell (1987) which failed to find significant correlations between performance on different measures of auditory discrimination. However, it has already been suggested that some outlying scores may have affected the analysis in the Bountress (1984) study. The finding of significant correlations in the data reported here may reflect, to some extent, the use of matched stimuli. The auditory discrimination picture task was more highly correlated with the ABX task which used matched stimuli, than with the same / different task which used different stimuli.

However, there were some differences in task performance. When performance was compared across the 3 tasks, using percentage of items correct, there were significant differences between task performance. Differences in task performance may be the result of cognitive factors, or of the different levels of speech input processing involved. Performance on the ABX task was poorer than on the auditory discrimination picture task and this may reflect differences between speech processing levels. The auditory discrimination picture task required the matching of spoken stimuli to existing phonological representations, and the ABX task required the comparison between two non-words for which there are no lexical representations. But performance on the ABX task could have been constrained by cognitive factors, such as the level of conceptual understanding required for the task, and / or attentional and STM demands in retaining two stimuli for comparison with a third.

For the same / different task, there was no effect on performance when words were presented rather than non-words. This suggests that for the stimuli and task used here, access to lexical representations did not aid discrimination. It is possible that the children tended to use bottom-up processing to discriminate both words and non-words.

It is difficult to make any further assumptions about the relationships between performance on different tasks because ceiling effects were present in the auditory discrimination picture task and the same / different task data, for the older children.

3.6.iii Differences in performance on speech production tasks.

Although performance was strongly correlated across the 3 speech production tasks, a significant main effect of task was revealed, with a significant interaction between age and task, suggesting a complex pattern of differences in performance for different ages of children.

For the 3 year-old children there was no significant difference in performance between word and NWR performance, however scores on both repetition tasks were significantly better than naming scores. The children were able to produce the target words in naming, with prompting where necessary, so poorer scores were not the result of children not knowing some of the words, or not recognising some of the pictures. As naming required the child to access their own lexical representations for production, this finding is interpreted to suggest that there were some inaccuracies / immaturities within these lexical representations for the youngest children. For repetition tasks, where bottom-up processing could support performance, the availability of the adult's models led to better performance. In repeating stimuli, there was no effect on production of existing lexical representations of the real words, as opposed to the non-words.

At the age of 4 years, word repetition had become significantly more accurate than NWR, suggesting that by this age the use of existing lexical representation had an advantageous effect on speech production. Word repetition was still significantly better than naming, suggesting that any inaccuracy / immaturity of lexical representations is still affecting naming performance. Whereas in the word repetition task the child hears an adult

model of accurate pronunciation and has an opportunity to update an immature motor program.

For 5 year-old children there is no longer any significant difference in performance between word repetition and naming, suggesting that lexical representations have matured and become more accurate. NWR continues to be significantly less accurate than the speech production tasks that use words, suggesting that there is a beneficial effect of lexical representation on output speech processing. This pattern was maintained in the 6 and 7 year-old children.

In the youngest children there was no significant difference between word and non-word repetition accuracy, however performance on these two tasks becomes increasingly divergent with age, with a greater rate of increase in accuracy for word repetition rather than non-word. Young children are frequently exposed to unfamiliar words and phonological forms and seem to have a facility to quickly learn how to say them (Rice, 1990). Their usual response on hearing new words is to repeat them (Speidal, 1989, cited in Gathercole et al., 1994). So the pattern of performance observed may reflect some facility with NWR at this younger age that aids new word learning, but that is subsequently weakened. Another possibility is that the 3 year-old children process both words and non-words presented for repetition in a similar way, favouring a bottom-up approach to both in which no use is made of lexical representations. It might be possible to illustrate this by analysing errors in word and non-word repetition. If bottom-up processing is being used, one would expect to find that non-words would not be lexicalised and that words would sometimes be produced as non-words. If top-down processing is occurring,

one would expect to find some lexicalisation of non-words. It would be interesting to carry out such an analysis and compare errors of lexicalisation and non-lexicalisation across age groups, to see if the younger children are tending to use bottom-up processing to do these tasks more than older children are.

The finding that in the older age groups, children are less accurate in NWR than in naming or word repetition could be interpreted in a number of ways. One possibility is that the STM requirement of holding a novel string of phonemes, as opposed to a known word, affects performance. This interpretation would be in accord with Gathercole et al. (1994b), who view NWR performance as being reliant on PSTM capacity. For the 3 year-old children, who showed no difference in word and non-word repetition performance, this did not seem to be a limitation. But one interpretation given to this finding above, was that both words and non-words presented for repetition were being processed bottom-up, in which case, if PSTM is influencing performance, it will have an effect on both sets of stimuli. However, it is equally possible that the speech processing requirements of either discriminating all the phonemes of the non-word without top-down support, or creating a new motor program could be affecting performance.

The effect of stimulus length in the speech production tasks was significant, with the children's responses being less accurate for longer words. There is a changing pattern of relationships between task and stimulus length across the age groups. For the 3 year-old children, word repetition is better than NWR, which is better than naming. The interaction between task and length approached significance, with naming affected

more greatly by word length than the repetition tasks. Lexical representations for longer words may be somewhat less accurate. For 4 and 5 year-old children there was no significant interaction between speech production task and stimulus length. Performance on naming and word repetition was better than performance on NWR. However, for the 6 and 7 year-old age groups there were significant interactions between task and length. The source of the interaction occurs as the relationship between naming and repetition performance changes with increasing stimulus length. For 2 syllable stimuli, naming and word repetition are significantly better than NWR, and there appears to be an advantage for lexical items. For 3-4 syllable stimuli, naming is not more accurate than NWR. Word repetition is significantly better than both naming and NWR. Lexical representations for longer items, as accessed in naming, appear to be less accurate, and NWR may be affected by the amount of novel phonological material to be processed. Word repetition is an easier task having the advantage of existing lexical representation, and an opportunity to update an inaccurate motor program using the spoken form heard. Measures of speech output processing in children aged 6 years and over, may be more sensitive to individual variation if multisyllabic stimuli are used.

Although there are some significant differences between task performances, the pattern of difference varies with age. However, performance on each of the speech production tasks was significantly correlated with performance on each of the other tasks, so that more accurate production skills seem to affect accuracy on all speech production measures. Naming was more highly correlated with word repetition than with NWR. This may reflect a lexicality effect for the children across the

whole age range, except those aged 3 years, or the fact that the same stimuli were used for the naming and word repetition tasks.

3.6.iv Correlations between speech production and auditory discrimination performance.

Performance on the three speech production measures of naming, word and NWR were significantly correlated with performance on the auditory discrimination picture task. For the 5 to 7 year-old children, performance on the naming and NWR tasks was significantly correlated with performance on all three auditory discrimination measures given to the older children. Performance on the word repetition task was not significantly correlated with the three measures of auditory discrimination. This is a surprising finding as word repetition is reliant to some extent on auditory discrimination skills. Children need to discriminate the word presented accurately enough to access an existing lexical representation, or to create a motor program, to produce the word. However, visual inspection of the means suggest that word repetition scores show the least difference across the 5 to 7 year-old age groups than any of the other tasks used, probably reflecting ceiling effects. This is may have reduced the correlation between word repetition performance and auditory discrimination task performance.

The findings of significant correlations between speech production and auditory discrimination tasks suggest that there may be an underlying global speech processing skill, or other cognitive factors(s), that affects performance on a range of both input and output speech processing tasks. However, it can also be argued that speech production is reliant on auditory discrimination skills. Firstly accurate discrimination will be important in the creation of accurate phonological representations and

motor programs (Stackhouse & Wells 1997, Vance, 1997) that will be used for output. Secondly, for repetition tasks children first have to discriminate the stimuli heard.

3.6.v Factors underlying performance on speech production and auditory discrimination.

To consider whether different factors are involved in input and output speech processing, data from all the tasks (for 5 - 7 year-olds) was entered into a factor analysis. This revealed that two factors were underlying performance, one that was influencing performance on auditory discrimination tasks and one that was influencing performance on speech production tasks. It would, therefore, seem that different factors are important in input and output speech processing, and these might be considered as separately developing systems to some extent. The factor underlying auditory discrimination task performance accounted for the greater amount of variability. As has been discussed above auditory discrimination skills may play some part in speech production performance and so account for some of the variance in speech production. This factor could also reflect attentional and / or cognitive skills which would be expected to affect performance on all tasks, but more particularly auditory tasks, which may be more cognitively demanding. However, the auditory discrimination picture task also loaded onto the auditory factor and this task even the youngest children found relatively easy, being undemanding of attention or conceptual understanding.

It seems reasonable to suppose that articulatory skills and / or phonological development would underlie performance on all the speech production tasks, but may not affect auditory discrimination task performance.

However, it is interesting to note that lexicality did not emerge as an underlying factor in task performance, as the factor analysis did not group together the production and discrimination tasks that used non-word stimuli. Neither did influence from a STM factor affecting performance emerge, in that auditory discrimination tasks carried different STM demands, but these were not differentiated in the factor analysis. So factors that are responsible for the input and output speech processing skills needed for such tasks are greater than any influence of STM capacity, and similar skills are needed to process both words and non-words.

The analysis suggests that, despite correlations between the range of speech processing tasks, performance on speech production tasks and auditory discrimination tasks might show some disassociation. In assessing speech processing skills at least one input and one output task should be used.

3.7 CONCLUSION

This experiment has found age effects in performance on a range of speech production and auditory discrimination tasks. This suggests that the tasks selected are developmentally sensitive, particularly for the younger children. There are differences in performance on the range of tasks, which support the hypotheses made. These differences are interpreted to suggest that the differing speech processing requirements within the range of tasks used affect performance. Useful experimental data can, therefore, be obtained by using a range of speech processing tasks and both lexical and non-lexical stimuli. There are some common factors to speech processing tasks, as revealed in the strong inter-task correlations, However, there are

likely to be different processing factors operating between input and output tasks.

The NWR task used here as a measure of speech processing, is also used as a test of PSTM by other researchers (e.g. Gathercole et al., 1994, Montgomery, 1995a). The data from this task will therefore be analysed further in Chapter 4.

CHAPTER 4:
EXPERIMENT 2: NON-WORD REPETITION AND SPEECH PROCESSING SKILLS

4.1 INTRODUCTION TO CHAPTER

Non-word repetition (NWR) has become a popular task in recent years in research in the fields of cognitive and developmental psychology and neuropsychology. A body of literature describes NWR as a measure of 'phonological working memory' or 'phonological short-term memory', and interprets difficulties with NWR as being the result of phonological short-term memory (PSTM) deficits (e.g. Gathercole et al., 1994).

Other groups of researchers have used NWR as a measure of speech processing skill. On this view difficulties with NWR are seen as the result of speech processing deficits at one or more levels of processing. For example, clinical investigations of children with speech disorders have involved the use of NWR as one of a range of matched tasks that tap different levels of the speech processing chain. This approach is considered to allow levels of processing deficit to be identified (Stackhouse & Wells, 1997, Bryan & Howard, 1992, Stackhouse & Snowling, 1992, Williams & Chiat, 1993).

The main focus of this chapter is to look at NWR separately from the short-term memory (STM) system, and to consider how the speech processing system deals with unfamiliar phonological material. The relationship found between NWR and speech production tasks, as shown in the significant interaction between age and performance on different

speech production tasks, was reported in Chapter 3 (p. 121). This chapter considers the relationship between NWR and auditory discrimination and speech production.

Firstly, research findings will be presented that reflect on:
Non-word repetition as a phonological short-term memory task
NWR as a speech processing task
Lexical influences on NWR performance.

Secondly, the experimental data collected in Experiment 1 (see Chapter 3) is re-analysed to consider, in more detail, the relationship between NWR and other measures of speech processing skills.

4.2 INTRODUCTION TO EXPERIMENT

4.2.i Non-word Repetition as a Phonological STM Task

NWR was initially chosen as a measure of working memory because it was simpler and faster to administer than traditional digit span tasks and it utilises non-lexical material, therefore results will not be confounded by varying degrees of familiarity with the material to be remembered (Gathercole & Baddeley, 1989). Studies have found effects of word familiarity on span in adults (Hulme et al., 1997) and in children (Henry & Millar, 1991) suggesting that familiarity with stimuli would be a confounding variable in measuring STM.

Other researchers have critically evaluated the use of NWR as a PSTM task. Snowling et al. (1991) have argued that several factors are involved in children's successful performance on such a task. Most notably, failure

might also occur due to difficulties with perception, with the storage of the phonological information, with segmentation of the phonological form, or in the execution of motor programmes for speech. They suggest that difficulties with these processes may affect NWR performance, and that phonological memory must be distinguished, theoretically, from other phonological processes. However, Bowey (1996) comments that "the argument that NWR reflects a range of skills does not deny that it also reflects phonological memory" (p. 47).

Gathercole et al. (1991) found a significant effect of word length (i.e. number of syllables) on NWR performance in children aged 4-6 years. They interpret this finding as evidence that NWR reflects PSTM capacity, in that longer nonwords require more capacity for storage. However, the longer a non-word is, the more phonemes have to be discriminated and produced, the greater the possibility there is for errors to arise. For instance, Gathercole et al.'s (1991) two-syllable non-words contain between 4 and 7 phonemes, whilst the four-syllable non-words contain between 8 and 13 phonemes. The non-word length effect may reflect this to some extent. In Chapter 3, significant word length effects were reported for naming and word repetition, with significantly poorer production of longer words. These tasks are not usually considered to entail a PSTM load as existing lexical representations for the words are utilised directly.

NWR performance has been found to be related to other measures of STM. Digit span and word span have been found to be significantly correlated with NWR in 4 and 5 year-old children (Gathercole & Adams, 1994, Gathercole, 1995a, Adams & Gathercole, 1996, Gathercole et al., 1999, Adams & Gathercole, 2000). This finding was confirmed in 5 to 6 year-old

and 8 year-old children (Michas & Henry, 1994, Gathercole et al., 1992). Gathercole and Adams (1993) found NWR to be significantly correlated with digit span in children aged 2 to 3 years, however, this correlation was not significant in a later study examining a sub-set of this group of children (Adams & Gathercole, 1995). So this relationship may not be robust. Gathercole (1995a) showed that NWR was significantly correlated with digit span in children aged 3, 4 and 5 years. However, the correlation was smaller at age 3 years than at age 4 and 5 years. Taylor, Lean & Schwartz's (1989) study indicates that, for children with language difficulties, NWR was significantly correlated with digit span. They concluded that poor NWR was the result of "an impairment in one or more processes by which phonological information is stored, manipulated or accessed in memory" (p. 215).

Another contribution to this debate comes from Metsala (1999). Metsala (1999) found that NWR and digit and word span were significantly correlated with each other. However, STM only contributed 8% of the variance to NWR after age and phonological awareness were forced into the equation, and phonological awareness accounted for approximately 7% of variance in NWR after age and STM were forced into equation. This suggests that other phonological processing skills are probably as important to NWR as the functioning of the phonological loop in STM may be.

If NWR is a measure of PSTM then one would expect it to reflect some of the same mechanisms found in the STM research. A word-length effect on NWR has been found, as reported above, however, this is open to other interpretation. Whilst there do not seem to be any published studies of

phonological similarity or concurrent speech effects on NWR, NWR was found to be significantly correlated with speech rate in 2 to 3 year-old and 4 and 5 year-old children (Gathercole & Adams, 1993, 1994).

4.2.ii NWR as a Speech Processing Task

A number of researchers have discussed the speech processing elements of NWR, for example perceptual and encoding skills (Bishop, 1997) and motor programming skills (Stackhouse & Wells, 1997).

The speech processing requirements of NWR have already been presented in Chapter 3 (p. 99) in terms of a developmental speech processing model (Stackhouse & Wells, 1997). It is apparent that auditory input processing skills and speech output processing skills, including motor programming skills are implicated in performance. It is because these different levels are involved that NWR is a useful task within the context of an investigation of speech processing in a child with a speech disorder. For example, motor programming skills can be isolated by comparing the child's performance on the NWR task with his ability to name pictures, or to repeat familiar words (Stackhouse & Wells, 1997). On this interpretation, the efficiency of input and output speech processing skills, as well as working memory capacity, would be expected to affect performance on NWR.

A number of other researchers have also outlined the speech processing levels that might be involved in NWR. Leitao, Hogben and Fletcher (1997) suggest that accurate NWR requires accurate perception and analysis of the stimuli in order to compile an output articulatory motor programme. They also suggest that "this type of task should prove clinically useful in screening children with clear speech for potential subtle language impairments" (p. 102).

Dollaghan, Biber and Campbell (1995) provide more detail of what might be involved in the analysis of the stimuli. They describe NWR as requiring the encoding of acoustic-phonetic strings as phonemes and syllables, the marking of units according to their temporal sequence, and the use of this representation of phoneme sequences to guide preparation and execution of a motoric program for articulating the string. On analysing errors made in NWR they suggest that many of these may result from input and output processing, such as in discriminating between different voiceless plosives /p, t, k/ within syllables, or in producing reduced clusters, e.g. /sʌk/ for 'sluck'.

Evidence for the role of input processing in NWR comes from a study by Ceponiene, Service, Kurjenluoma, Cheour and Naeaetaenen (1999). Children aged 7 to 9 years were grouped on the basis of how good they were at NWR. The group with higher NWR scores were significantly better at discriminating between tones and speech syllables in a same / different task than the group with low NWR scores. There were also significant differences between the two groups on measures of the mis-match negativity component of event-related brain potentials when the stimuli were speech syllables. This measure is considered to tap a low-level of speech input processing, before any discrimination or recognition of the stimuli occurs. This evidence, therefore, suggests that the accuracy of NWR is affected by the accuracy with which sound stimuli are processed.

Further evidence for an association between NWR and speech input processing comes from a study in which variation between dyslexic and non-dyslexic children's accuracy of NWR was accounted for by

performance on same / different auditory discrimination and on a phoneme detection task. van Bon and van der Pijl (1997) argue that NWR difficulty is due to poor phonological segmentation ability and poor speech input skills, rather than to restricted phonological memory. This idea is supported by Grainger and Whiteley (1999) who found evidence that, for 4 to 6 year-old children, the ability to "segment the non-words into their constituent parts and then blend these together for recall" was important for NWR performance. Findings by Bowey (1996) that argue for the role of phonological awareness in NWR have already been discussed (Chapter 1, p. 33). However, NWR was not found to be closely linked with phonological awareness in a study by Kahmi and Catts (1986).

Gathercole and Adams (1993) found that NWR was more closely related to word repetition than to digit span in 2-3 year-old children. Word repetition and digit span both significantly predicted NWR in multiple regression. However, after age and non-verbal skills, word repetition accounted for additional variance of $r^2 = .38$ as the third step in the equation, whereas digit span accounted for additional variance of $r^2 = .11$ when this was the third step entered. This suggests that speech processing may be having more effect on NWR performance than STM skills. However, NWR accounted for slightly more of the variance in digit span than of the variance in word repetition.

NWR was significantly correlated with digit span and reading and spelling, but not with sound analysis and blending in a group of children with learning disabilities (Taylor et al., 1989). This contrasts with suggestions from van Bon and van der Pijl (1997) and Grainger and Whiteley (1999) that phonological segmentation skills may play a role in NWR.

Gathercole et al. (1991) considered the effects of a speech output 'articulatory' factor on NWR. Some of the non-words used in this study contained consonant clusters and some did not, in order to make a planned comparison of effects of complexity. There was no significant effect of consonant clusters (interpreted by Gathercole et al. to be articulatory complexity) on repetition performance. They concluded that NWR was not constrained by articulatory output factors. However, there was an unexpected finding of poorer performance on one syllable than on two syllable non-words. Gathercole et al. (1991) suggested this was because performance was particularly poor on two of the one-syllable items which contained difficult to discriminate sounds /f/ and /θ/. This seems to be an argument for input speech processing having a possible effect on NWR performance.

In contrast to the above finding, a significant correlation between number of consonant clusters within non-words and repetition accuracy for 4 and 5 year-old children was found by Gathercole (1995b). Multiple regression analyses showed that phonological complexity accounted for some of the variation in performance. It is not possible to determine exactly how much because this measure was entered into the equation at the same time as measures of number of syllables and number of phonemes. However, these findings may indicate some influence of speech processing skills on NWR. Bishop, North and Donlan (1996) also found an effect of articulatory complexity (i.e. whether or not the non-word contained a consonant cluster) on repetition in children with and without SLI.

Adams and Gathercole (1995) divided a sample of 3 year-old children into two groups based on their phonological memory composite scores (combining NWR with digit span scores). One group had poor phonological memory scores, and the other group had good phonological memory scores. The children were asked to repeat 'cat, nose' as quickly as possible, as a measure of articulatory skill. In the description given of children's performance it is clear that of the children who were unable to sequence repetition of this word pair three times, twice as many (13) were in the poor phonological memory group, than in the good phonological memory group (6). One way in which this incidental finding could be interpreted is that some of the children who had performed less well on NWR and digit span may have been less skilled in speech output, with difficulties in motor programming, motor planning and / or motor execution. Such speech output difficulties could have affected NWR scores and thus their composite memory score.

Gathercole et al. (1994b) acknowledge that children with motor programming difficulty are likely to show non-word repetition deficits. Indeed they caution that "in such cases, memory deficits should not be assumed to be the primary source of the repetition problem" (p. 124). However, there is no acknowledgement of the range of variation in motor programming skills that is likely to occur within the normal population, and which would affect NWR accuracy. Williams and Stackhouse (2000) report 'considerable individual variation' in accuracy in a group of 3-5 year-old children who do not have speech difficulties, when the task was the repetition of syllables. Here the memory loading is probably less than in NWR, as the same simple syllable sequences are repeated, but motor programming, planning and execution skills have affected performance.

Another finding that possibly reflects speech output effects in NWR comes from Gathercole and Adams (1993, 1994) and Gathercole et al. (1999). These studies found that speech rate was significantly correlated with NWR but not with digit span. This suggests that NWR performance may be more influenced by speech output skills than performance on other STM tasks might be. Gathercole et al. (1999) argue that this significant correlation is found because NWR is scored for accuracy of pronunciation, whereas for word span or digit span items mispronunciations are tolerated, as long as the response is recognisable.

There is some potential conflict in these two uses for NWR tasks. If speech processing skills are implicated in NWR performance, then use as a measure of phonological short term memory is compromised. On the other hand, the retention of non-word stimuli is necessary for processing the sequence of sounds for accurate repetition as a speech production measure and so this may be affected by phonological memory capacity.

4.2.iii Lexical Influences on NWR

One of the justifications for using NWR as a test of PSTM was that the use of non lexical stimuli, would eliminate familiarity with test material as a confounding factor in performance (Gathercole & Baddeley, 1989). NWR is used in investigations of speech processing skills to illustrate how a child deals with speech stimuli for which he / she does not have a lexical representation (Stackhouse & Wells, 1997), and in particular for which he / she has to create a new motor programme. However, findings from several recent studies have suggested that existing lexical knowledge does influence NWR performance.

Gathercole et al. (1991) rated a set of non-words on a 5 point scale for word-likeness. Children aged 4-6 years were asked to repeat the non-words and the more word-like non-words were repeated significantly more accurately than the less word-like non-words. This finding was replicated with children at ages 4 and 5 years (Gathercole, 1995b). A similar finding is reported by van Bon & van der Pijl (1997). 'Dutch' non-words were either constructed using high frequency onsets and codas, and therefore considered to be more word-like, or by using low frequency onsets and codas, considered to be less word like. Two and three syllable non-words that were designed to be more word-like were repeated significantly more accurately than less word-like non-words by children with and without reading difficulties.

A slightly different approach to examining the effects of lexical knowledge was used by Dollaghan, Biber and Campbell (1993, 1995). They found that children repeated non-words that contained stressed syllables that correspond to real single syllable words significantly more accurately than non-words in which none of the syllables corresponded to a real word. These authors hypothesise that the presence of a real word within the non-word allows the use of long term representations to maintain these parts of the non-words in memory. This frees up resources for the recall of the rest of the non-word. This idea ties in with that of Case et al. (1982), whereby STM capacity is considered to be shared by operating space and storage space, as discussed in Chapter 2 (p. 69).

Gathercole et al. (1991) also compared repetition performance of non-words containing root morphemes with repetition of those that did not

contain root morphemes. They did not find any significant difference between repetition of non-words with or without root morphemes. However, stress patterns were not given for these non-words, and some of the root morphemes may have occurred in unstressed positions within the words, thus accounting for a finding that differs from that of Dollaghan et al. (1993, 1995).

In analysing the errors made in repetition, Dollaghan et al. (1995) found that 51% of errors in NWR were the result of transforming non-word syllables into real words (lexicalisation), suggesting an effect of top-down influences on performance. They also comment that this occurs even when the non-word would be easier to articulate as presented. It is possible that this reflects motor programming constraints, in that it is easier to say what you know how to say, i.e. to tap into existing motor programmes, than it is to set up a new motor programme. These authors concluded that "the conception of phonological working memory as something that can be separated from lexical operations is open to question" (p. 221).

Gathercole (1995b) looked at the relationship between repetition of non-words with low and high word-likeness ratings and STM and language measures. Accuracy of repetition of the less word-like non-words was more strongly related to digit span and word span measures than accuracy of repetition of the more word-like non-words. Gathercole (1995b) argues that this is evidence for a greater contribution from PSTM for repetition of less word-like non-words than of more word-like no-words. However, the relationship between accuracy of repetition of more word-like non-words and vocabulary measures was less clear-cut, given that it might be expected that word-likeness effects were mediated by existing vocabulary

knowledge. Vocabulary knowledge at age 4 years was more strongly correlated with the accuracy of repetition of more word-like non-words at age 5 years, than of less word-like non-words. However, this was not the case for measures taken at the same point in time. Gathercole (1995b) argues that this forward relationship between vocabulary and repetition of more word-like non-words supports the view that lexical knowledge supports repetition accuracy for word-like non-words.

Another variable affecting NWR performance is explored by Gathercole and Martin (1996). One feature that was found to affect performance was the phonological neighbourhood characteristics of the non-word. That is, the number of words that differed by one-phoneme from the non-word. This measure accounted for significant variation in the rating of a non-word as being more or less 'word-like' and studies have been reported above that show that non-words with high-wordlike ratings are repeated more accurately than non-words with low-wordlike ratings. Gathercole and Martin (1996) suggest that "wordlikeness judgements are indeed based, either directly or indirectly, on the lexical density of the phonological space occupied by the non-words" (p. 83). This provides one explanation to the findings of word-likeness effects on NWR presented above (Gathercole et al. 1991, van Bon & van der Pijl, 1997). Non-words with more phonological neighbours within the lexicon are more likely to access existing lexical representations and tend to be repeated more accurately than those with fewer phonological neighbours.

The locus of word-likeness effects was considered to be in input processing, in a study comparing English-French bilingual children, presented with non-words that accorded with English or French

phonological structures (Thorn & Gathercole, 1999). Significant wordlikeness effects were only found when the non-word stimuli were in the child's native language. Gathercole and Martin (1996) concluded that the wordlikeness effect arises from language-specific specialisation that arises early in speech perception development, (possibly at the level of phonological recognition posited in the Stackhouse and Wells (1997) speech processing model presented in Chapter 2 (p. 49). However, these effects may also arise at an output level of motor programming, in that it may be easier to create motor programmes for non-words, or new words that accord to the phonotactic structures of one's more familiar language.

These reported effects of word-likeness and constituent words in non-word stimuli may arise from lexical support for recognition of the non-word stimuli in input. If similarities between the non-word and existing phonological representations are recognised this may make it easier to decode the stimuli and to maintain it in STM, possibly with support from the 'redintegration' process that has already been referred to in Chapter 2 (p. 75). However, it is also possible that similarities with existing lexical representations, may allow existing motor programmes to be utilised, either in part or in whole, during the speech production of the non-word.

Non-word stimuli, if freely generated, as in Gathercole et al. (1991) are likely to result in the inclusion of word forms and morphemes, and therefore a word-likeness effect, because top-down language processing will influence the experimenters spontaneous generation. Non-words that are more methodically created, as in the system used in this study (see Chapter 3, p. 110) may be less likely to be word-like, because they are being composed according to laid down criteria.

Wearmouth (1996) compared accuracy of NWR across different sets of stimuli, in children aged between 4 and 7 years. One set contained 20 of the non-words created by Gathercole et al. (1994b) and another set contained 20 of the non-words constructed for the experiment reported in the previous chapter. These non-words were constructed by changing the vowels within a set of real words. The Gathercole et al. (1994b) non-words were repeated significantly more accurately than the non-words created by changing the vowels. The two sets of non-words were matched for length. There were 9 non-words containing clusters in the Gathercole et al. set, and only 2 containing clusters in the 'vowel change' set. So the difference in accuracy did not arise from a complexity effect. Given the reports of effects of wordlikeness on NWR, this finding may support the argument above that non-words created to criteria are less likely to be word-like than non-words that are freely generated. Whether NWR is being carried out as a task of PSTM or of speech processing and motor programming, it would seem to be desirable to reduce wordlikeness effects as far as possible.

4.3 RATIONALE FOR THIS EXPERIMENT

The literature shows that NWR has been used as a measure of PSTM and of speech processing, and speech processing skills have been found to be related to NWR skills. This study investigates the relationship between NWR and speech input and output processing skills, in a context where STM demands are considered to be minimal. Accuracy of NWR was compared with another speech production measure, naming, and with the auditory discrimination picture task. These measures were selected because they have relatively low STM demands, only one stimulus was presented at

a time, and picture support was available. Any relationship found with NWR should reflect common speech processing skills rather than common STM capacity demands.

4.3.i Predictions

The naming task taps all levels of speech output processing, from motor programme to motor execution. As described above STM requirements are minimal. If speech output processing skills affect accuracy of NWR, then children's performance on a naming task, will account for a significant proportion of the variation in NWR performance.

The auditory discrimination picture task taps all levels of speech input processing, from peripheral auditory processing to phonological representation. As described above, STM requirements are minimal. If speech input processing skills affect accuracy of NWR, then children's performance on the auditory discrimination picture task, will account for a significant proportion of the variation in NWR performance.

4.4 METHOD

Data collected in the experiment outlined in the previous chapter, Chapter 3, is used in this study.

4.4.i Experimental Design

This experiment investigates the relationships between 3 within subject variables. These were performance on the naming, NWR and auditory discrimination picture task.

4.4.ii Participants

Data was collected from 100 children aged between 3 and 7 years of age. Full details of participants and of selection criteria are given in Chapter 3, (p. 104).

4.4.iii Materials and Procedures

The data from 3 of the tasks presented in Chapter 3 is used in this study:

Naming

Non-word repetition

Auditory discrimination picture task.

Details of these tasks, stimuli and procedures have already been described in Chapter 3, p. 105 - 112. The full experimental procedure is also reported in Chapter 3, p 112-113.

4.5 RESULTS

As has previously been reported in Chapter 3, the auditory discrimination picture task data did not show a normal distribution, with observable ceiling effects present. Correlational analyses were, therefore carried out using a nonparametric procedure, Spearman's rho (see Table 4.1). NWR was significantly correlated with naming and with auditory discrimination, and naming was significantly correlated with auditory discrimination.

Table 4.1: Spearman's rho correlations across tasks.

	Naming	**NWR**	**Auditory disc picture task**
Naming	1.00	.736**	.487**
NWR		1.00	.529**
Auditory disc picture task			1.00

** Significant at the level of p <.01

A series of hierarchical multiple regression analyses was carried out to determine whether speech production skills and / or auditory discrimination skills explained a significant amount of variation in NWR. NWR was the dependent variable and naming and auditory discrimination picture task were the predictor variables. Where two predictor variables are strongly correlated, as are naming and auditory discrimination picture task (see Table 4.1), there is an issue of collinnearity to consider. However, this is likely to result in reduced significance of the additional contribution of the second predictor variable (Cohen & Cohen, 1983, p115). If the predictor variables are found to be significant contributors to variance in NWR, then collinearity will result in this being underestimated rather than over estimated.

Examination of the residuals showed that 4 participants showed standard residuals of greater than 2 standard deviations. The data from these participants was, therefore, omitted from the regression analysis. As age effects were reported on all 3 tasks in Chapter 3, age was entered as the first step in the equation, this allowed the effects of age on variation in NWR to be accounted for. Naming and auditory discrimination picture task

performance were then entered as the second and third steps of the equation in turn.

Table 4.2: Hierarchical multiple regression analyses predicting accuracy of NWR in 3 to 7 year-olds.

Dependent variable: NWR

	Variable	R^2 change	Probability
Step One	**Age**	.345	<.001
Step Two	**Naming**	.300	<.001
Step Three	**Aud. discrimination**	.090	<.001
Step Two	**Aud. discrimination**	.291	.001
Step Three	**Naming**	.099	<.001

Age was found to account for 35% of the variation in accuracy of NWR (see Table 4.2) and this was significant at p<.001. When naming was entered as the second step it accounted for an additional 30% of the variance, with auditory discrimination as a third step accounting for a further 9% of the variation in accuracy of NWR. Both these models were highly significant. When auditory discrimination was entered as the second step it accounted for an additional 29% of the variation, whilst naming entered as a third step accounted for a further 10% of variation in accuracy of NWR. Again, both these models were highly significant. So both naming and auditory discrimination seem to be accounting for significant amounts of unique variation in NWR.

As a significant interaction between performance on different speech production tasks and age was found in the analysis in Chapter 3, the regression analysis were repeated, to see if the models predicted in the same way across different age groups.

Table 4.3: Hierarchical multiple regression analyses predicting accuracy of NWR in 3 and 4 year-olds.

Dependent variable: NWR

	Variable	R^2 change	Probability
Step One	**Age**	.173	.020
Step Two	**Naming**	.522	<.001
Step Three	**Aud. discrimination**	.121	<.001
Step Two	**Aud. discrimination**	.493	<.001
Step Three	**Naming**	.120	<.001

In the children aged 3 and 4 years, age was found to account for 17% of the variation in accuracy of NWR (see Table 4.3) and this was significant at $p<.001$. When naming was entered as the second step it accounted for an additional 52% of the variance, with auditory discrimination as a third step accounting for a further 12% of the variation in accuracy of NWR. Both these models were highly significant. When auditory discrimination was entered as the second step it accounted for an additional 49% of the variation, whilst naming entered as a third step accounted for a further 12% of variation in accuracy of NWR. Again, both these models were highly significant. For these younger children, both predictors seem to

account for greater unique variation in NWR performance, than is the case in the wider age range reported above.

Table 4.4: Hierarchical multiple regression analyses predicting accuracy of NWR for 6 and 7 year-olds.

Dependent variable: NWR

	Variable	R^2 change	Probability
Step One	**Age**	.170	.010
Step Two	**Naming**	.245	.001
Step Three	**Aud. discrimination**	.060	.056
Step Two	**Aud. discrimination**	.174	.004
Step Three	**Naming**	.131	.006

For the 6 and 7 year old children, age was found to account for 17% of the variation in accuracy of NWR (see Table 4.4) and this was significant at $p<.001$. When naming was entered as the second step it accounted for an additional 24% of the variance, and this was significant, with auditory discrimination, as a third step accounting for a further, non-significant, 6% of the variation in accuracy of NWR. When auditory discrimination was entered as the second step it accounted for an additional 17% of the variation, whilst naming entered as a third step accounted for a further 13% of variation in accuracy of NWR. Both these models were highly significant. For these older children, naming and auditory discrimination do not predict as much variation in NWR as these skills do in the younger children.

4.6 DISCUSSION

Significant age effects on performance in naming, NWR and the auditory discrimination picture task (found in the data analysis reported in the previous chapter) suggest that any relationship between task performances could be the result of age differences rather than processing skills. However, partial correlations indicated that significant relationships between performance on NWR and both naming and auditory discrimination remained even when effects of age had been removed. The regression analyses also found significant relationships between task performances after age had been entered as the first step of the equation.

The results of the series of multiple regression analyses indicated that although age was a significant predictor of NWR, speech output skills, as measured by naming, and speech input skills, as measured by auditory discrimination scores accounted for significant amounts of variation in NWR. The associations found between these tasks may reflect to some extent the close matching of the stimuli for the 3 tasks, in terms of phonological structure. There are also word length effects of similar magnitude operating on naming and NWR (as reported in Chapter 3, p. 125), and there may also be word length effects on the auditory discrimination picture task, although these have not been examined. However, there was some difference in the strength of these associations at different ages, suggesting that any effects of length and / or similar stimuli are not accounting for all of the variation predicted.

In younger children, aged 3 and 4 years, the speech processing measures accounted for at least twice as much of the variance in NWR as in the older

children, aged 6 and 7 years. For the younger children naming and auditory discrimination accounted for 52% and 49% of the variance when entered as the second step in the equation after age. For the older children, these percentages were 24 % and 17% respectively. For these older children some other factors might become more significant in predicting NWR. So for the whole group and for the younger children, there is little difference in the amount of variance that either naming or auditory discrimination predicts, when entered as the second step. In the older group naming accounts for rather more variance than auditory discrimination does when entered as a second step.

When naming or auditory discrimination was entered as the third step in the equation, again there is little difference in the amount of variance that each predicts, for the whole group and for the younger children. In the older group when auditory discrimination is entered as the third step in the equation, after age and naming, it accounts for 6% of additional variance, and this does not quite reach significance. When naming is entered as the third step in the equation, after age and auditory discrimination, it accounts for 13% of additional variance, and this is significant. This suggests that whilst for the younger children both speech processing measures carry almost equal weight in predicting NWR, for the older children naming makes a greater contribution to predicting NWR. It may be that the ceiling effects on the auditory discrimination data affect the analysis.

Speech output skills, as measured by naming scores, are clearly predictive of accuracy of NWR. Gathercole and Adams (1993) found that word repetition, another speech production measure, significantly predicted accuracy of NWR. These two tasks were also significantly associated with

speech rate and Gathercole and Adams (1993) suggest that the repetition measures are "directly constrained by the child's speech production measures" (p. 776). The relationship between naming and NWR might arise from the effect of children's individual levels of phonological development on performance. For example, if a child is reducing clusters, saying /sun/ for 'spoon', then this process will operate on both naming and NWR and affect scores for both tasks, especially as the stimuli for both naming and NWR were matched for consonants. The greater contribution of naming in accounting for variance in NWR in younger children, rather than older children, may arise as a result of greater variability in the phonological development of pre-school children. By the age of 6 years, phonological development is likely to be almost complete, with children using adult-like realisations of most words. Sahlen et al. (1999b) found NWR to be correlated with stages of phonological development in children with SLI.

Speech input skills also clearly make a contribution to the accuracy of NWR, although there is less additional variance attributable to auditory discrimination in the older group, after age and naming have been entered. Non-words must be perceived and discriminated accurately before accurate motor programmes can be constructed for production of the non-word. It is, therefore, unsurprising that auditory discrimination skills predict some of the variation in NWR accuracy. The finding that word-likeness effects on NWR may be partly mediated by the number of phonological neighbours a non-word has (Gathercole & Martin, 1996) may be pertinent. Children with good auditory discrimination skills are more likely to have a larger number of better quality phonological representations, and, therefore, have a greater phonological neighbourhood effect on NWR.

4.7 CONCLUSION

This experiment was designed to understand NWR in the context of the processing of speech. The hypotheses of significant relationships between speech input and output processing skills and accuracy of NWR have been supported. The data reported here supports the notion that speech processing skills have a significant effect on performance on NWR, which has been used as an experimental measure of PSTM. This suggests that the role of speech processing skills in so-called memory tasks must be acknowledged. Performance on NWR tasks may be affected by integrity and efficiency of speech processing skills. However, speech processing skills may have more influence on NWR performance in younger children than in older children. The relative contribution of STM skills to NWR also needs to be considered. An experiment in which measures of speech processing skills and STM can be compared in the prediction of NWR accuracy will be presented in Chapter 6.

CHAPTER 5

EXPERIMENT 3: THE EFFECTS OF TASK PRESENTATION AND COMPLEXITY OF STIMULI ON STM PERFORMANCE

5.1 INTRODUCTION TO CHAPTER

This chapter examines the effects of speech systems, i.e. auditory discrimination and speech production on short-term memory (STM) performance. As has already been discussed in Chapter 2, various aspects of speech processing seem to play a role in STM. STM tasks often use spoken presentation and / or responses. Researchers have used a number of different task paradigms to examine STM recall in young children. The children may be asked to listen to a list of words and repeat them (Hulme, 1987, Hitch et al., 1989a) or point to pictures of them (Adams & Gathercole, 2000). They may be presented with a series of pictures and asked to point to the same pictures in recall (Hulme, 1987, Hulme, Silvester, Smith & Muir, 1986, Hitch et al., 1989a). The children may be shown a series of pictures and asked to say the names of the pictures in recall (Hitch et al., 1989a, Hitch et al., 1989c, Longoni & Scalisi, 1994). Some researchers have compared task performance using two or more of these paradigms (Hulme, 1987, Hitch et al., 1989a), and a range of findings have been presented.

The word-length effect on STM tasks is robust and is found in a number of studies (reviewed in Baddeley, 1986) This effect has been interpreted to suggest that spoken duration of material to be remembered affects recall (Baddeley, 1986). An alternative view is that the amount of material in

terms of phonological units, such as number of syllables or of phonemes, determines recall.

This chapter evaluates some of the research findings on:

i) Different STM task presentation and response mechanisms,

ii) Word length effect.

The experiment reported examines two aspects of STM performance:

i) Whether there are differences in performance when presentation and response mechanisms for STM tasks are varied;

ii) Whether the number of phonemes in stimuli may be, in part, responsible for the word length effect on STM performance.

5.2. INTRODUCTION TO EXPERIMENT

5.2.i STM Task Paradigms

As suggested above the input and output mechanisms used in STM tasks may be auditory / verbal or visual / pictorial. Different combinations of presentation and response mode can be used. It is possible to examine the speech processing demands of these tasks, in the same way as auditory discrimination and speech production tasks were analysed in Chapter 3. Again, this is based on the Stackhouse and Wells (1997) speech processing model.

1. SISO, Spoken Input – Spoken Output Task. Stimuli are presented in a spoken form and recall is spoken. Speech input processing, from peripheral auditory processing to phonological representation, and speech output processing, from motor programme to motor execution, is involved (see Figure 5.1).
2. SIPO, Spoken Input – Picture-pointing Output Task. Stimuli are presented in a spoken form and recall is by picture-pointing. Speech

input processing, from peripheral auditory processing to semantic representation is involved, but speech output processing is not (see Figure 5.2).

3. PISO, Picture Input – Spoken Output Task. Stimuli are presented in a pictorial form and recall is spoken. Speech input processing is not involved, but speech output processing, from semantic representation to motor execution is involved (see Figure 5.3).

The research has concentrated on the input mechanism of spoken words or picture presentation, with less attention paid to the response mechanism. Speech processing models would predict differences in performance for pictorial and spoken presentations and responses. Although some studies have used different task paradigms with children, analysis has not always considered differences in performance of the two types of stimuli, in terms of number of items correctly recalled (Hulme, 1987, Hitch et al., 1989a).

Adams and Gathercole (2000) presented two STM tasks to 4 year-old children. In both tasks, the stimuli were presented verbally and the response was either spoken (i.e. SISO) or by pointing to pictures (i.e. SIPO). There was no significant difference in recall between the spoken response condition and the picture-pointing response condition. Visual inspection of the data suggested that a small number of children (4 out of 30) produced longer spans when the response was pointing to a picture (SIPO) than when the response was spoken (SISO). Lovatt, Avons and Masterson (2000) also used a spoken presentation with different response mechanisms, with adults. However, they did find significantly greater recall for the picture pointing response (SIPO) than for the spoken response (SISO).

Figure 5.1: Speech processing for Spoken Input – Spoken Output task (after Stackhouse & Wells, 1997)

Figure 5.2: Speech processing for Spoken Input – Picture-pointing Output task (after Stackhouse & Wells, 1997)

Figure 5.3: Speech processing for Picture Input – Spoken Output task (after Stackhouse & Wells, 1997)

A key issue is the process by which pictorial stimuli are remembered, as compared to spoken stimuli. The phonological loop component of the WM model assumes that spoken material enters the phonological short-term store, and is maintained by the sub-vocal rehearsal process. However, for picture material it is less clear. The WM model proposes that visual inputs have access to the phonological loop, but that the material first has to be recoded in a speech-based form through the sub-vocal rehearsal process. This recoded material can then be maintained in STM in the same way as spoken material. Researchers have found differences in the way in which children recall spoken and picture material. A major focus of research has been the stage of development, and the age, at which the facility to recode picture material in a speech-based form, and hence, use of the phonological loop to recall picture material, comes into play. Development of the sub-vocal rehearsal process has been discussed in Chapter 2. Reviews of the evidence suggest that this does not emerge until the age of 7 or 8 years (Gathercole & Martin, 1996, Henry & Millar, 1993, Baddeley et al., 1998).

These issues have been addressed by using the variables of phonological similarity and word-length in experimental studies to test whether the phonological loop is being utilised for picture recall. Serial recall tasks for pictures showed effects of both phonological similarity (Hulme, 1987, Ford & Silber, 1994) word-length and concurrent speech (Hulme et al., 1986) in children aged from 4 years to 10 years. Hitch, Halliday, Schaafstal and Schragen (1988) also found a small word length effect on recall of pictures by 5 year-olds. These findings suggest that 4 year-old children are using speech coding, i.e. the phonological loop, as a means of memorising pictorial material. However, not all studies have confirmed

these findings. Hitch et al. (1989a) reported that children did not show any significant effect of word length on recall for pictures until after the age of 8 years. There was no significant effect of phonological similarity on picture recall for 5 year-old children (Hitch et al., 1989c, Longoni & Scalisi, 1994) or for 3 year-old children (Palmer, 2000). Six and seven year-old children did show a phonological similarity effect, suggesting use of a speech-based code (Palmer, 2000). However, Palmer noted that there were individual differences in the age at which phonological recoding began to be used, with phonological similarity effects found in some children as young as 5 years, but absent in some children at age 8 years.

There are differences in task presentations across these studies which might account for some of the variation in findings. In some studies the tester presented the pictures for recall silently (e.g. Hitch et al., 1989a, Hitch et al., 1989c, Longoni & Scalisi, 1994). In others the tester also named the pictures as they were presented (Hulme et al., 1986, Hulme, 1987), or requested the child to name the picture as it was presented (Hitch, et al., 1988). If the pictures were named by tester or child at presentation, then this might trigger the recoding of picture material into a speech based form. Hulme et al. (1986) named the pictures to half of the children in their experiment, and presented the pictures silently to the other half. There was no significant effect of experimenter naming on recall. However, this is in contrast to the finding of Ford and Silber (1994). They compared children's recall of pictures when the children named the pictures and when they were encouraged to remain silent. The children aged 3 to 5 and 5 to 11 years remembered significantly more words in the naming than in the silent condition, and this was more marked in the younger group. Palmer (2000) found that there was no significant

difference in recall for 3, 6 and 7 year-old children whether they were asked to name the pictures presented or had been asked to remain silent.

Another influential task variable is whether or not the children spontaneously name the pictures presented. In the studies by Hitch et al. (1989a), and Hitch et al. (1989c) the tester presented the pictures silently. The children were either told not to say the names of the pictures aloud, although they could "do what you like in your head", or to silently name the pictures " with your lips". Recall was spoken. There was no effect on performance of allowing the children to silently name, however there was a significant interaction between word length and naming, suggesting that naming was more important for maintaining longer words in STM. Hulme et al. (1986) monitored the children's subvocal speech movements, without putting any restrictions on the child naming the pictures as they tried to remember them. Four year-old children tended to overtly name the pictures they were recalling, and a proportion of older children used sub-vocal rehearsal. It may be that this naming of the pictorial stimuli, overtly or sub-vocally, by the children generated the stimuli in a speech-based form that could be retained in the phonological loop for recall. Hitch et al. (1989a) and Hitch et al. (1989c) were in effect preventing the young children from using the mechanisms and strategies available to them. This may be more important for younger children who tended to spontaneously overtly name the pictures in Hulme et al's (1986) study.

A third factor that may influence whether or not the phonological loop is used to recall picture material in young children, is the response mode. It is possible that if recall is spoken, children will tend to recode the pictures in a speech based form at presentation, whereas if recall is through a picture-

pointing response they might not. However, Hitch et al. (1988, 1989a) and Longoni and Scalisi (1994) argue that before the age of 7 years, phonological coding only occurs at the time of spoken recall. This seems to be confirmed by Ford and Silber (1994) who used a spoken response, but only found phonological similarity effects when the children had labelled the pictures at presentation. Palmer's (2000) study also used a spoken response, but did not find a phonological similarity effect in younger children.

The differing conditions under which experiments have been carried out may account for the differences in findings. Whether or not the tester or child names the pictures as they are presented, and if the response is spoken, rather than pictorial, affects the degree to which speech processing skills might be implicated in performance.

Picture recall has been found to be affected by visual similarity effects in younger children (Hitch et al., 1988, Longoni & Scalisi, 94). This is interpreted to suggest that visual strategies and the visuo-spatial scratchpad are implicated in picture recall. Although, again findings have been mixed. For example, Hitch et al. (1989a) found no significant effect of visual similarity (elongated objects portrayed at the same 45' angle) on picture recall in children aged 4 years and over.

It is clear that there may be differences in performance on STM tasks that use different modes for presentation of stimuli and for response. These may reflect the STM mechanisms involved, such as the way in which stimuli are coded. They may also reflect the differing levels of speech processing involved. Where direct comparisons have been made for

performance across a range of paradigms (Adams & Gathercole, 2000, Lovatt et al, 2000) findings are inconclusive, and only 2 of the possible 3 paradigms are used.

5.2.ii Spoken Duration in STM Performance

Findings of a significant effect of word length on recall gave rise to the suggestion that the capacity of the phonological loop is limited (Baddeley et al., 1975). Word length effects have been found in STM recall for spoken words in young children (Hitch & Halliday, 1983, Ford & Silber, 1994, Gathercole & Adams, 1994, Hulme et al., 1984).

Word length effects have been linked with spoken duration of material and speech rate. The view is that longer words take longer to say, take longer to rehearse, and therefore, fewer of them can be maintained within the phonological loop. Baddeley et al. (1975) argue that the word length effect is due to the articulatory duration of words, and not just to the number of syllables within the words. They carried out a study in which recall of two syllable words, with short durations, e.g. 'wicket' and 'bishop', was compared to recall of two syllable words, matched for number of phonemes, but with longer durations, e.g. 'harpoon' and 'Friday'. Significantly more of the shorter words were recalled suggesting that the phonological loop is sensitive to the articulatory length of the stimuli, rather than the number of syllables. This finding was confirmed by Cowan et al. (1992) who also compared recall of words with shorter or longer articulatory durations, matched for number of phonemes and number of syllables and found that more of the shorter words were recalled.

However, Caplan, Rochon and Waters (1992) and Caplan and Waters (1994) did not find the expected word length effects when comparing span for lists of two syllable words that were matched for number of phonemes and syllables, but differed for articulatory duration. The spoken duration of the words was manipulated by choosing words with short vowels, e.g. 'picnic' or words with at least one long vowel in them, e.g. 'balloon'. In fact there was significantly better recall for the words of longer duration, than for the shorter words. A further experiment (Caplan et al., 1992) matched sets of stimuli for the number of phonemes and syllables, but differed in articulatory complexity, using CCV words like 'crow' versus CVC words like 'hat'. There was a significant difference in articulatory duration, with the CCV words taking longer to articulate than the CVC words. But there was no significant difference in recall between the difficult-to-say (i.e. CCV) and the easy-to-say (CVC) words. These two findings led Caplan et al. (1992) to conclude that word length effects were determined by phonological structure and not by features of articulatory length, and that they arise at the level of speech output processing with the increased complexity of planning motor speech gestures.

This issue of articulatory complexity is another hypothesis to consider in interpreting word length effects longer words will require more complex motor planning, because they will contain more phonemes and syllables, and will be more likely to contain consonant clusters. Effects of articulatory complexity have been found in NWR in children, with non-words with clusters being harder to repeat accurately than non-words without clusters (Gathercole & Baddeley, 1989, 1990b, Bishop et al., 1996).

A further interpretation of word length effects on recall is that it is the amount of phonological material to be recalled that is significant, rather than the time taken to say it, or its articulatory complexity. On this view the phonological loop might be considered to have a capacity for number of units (i.e. phonemes to be recalled) rather than a time- based capacity.

Lovatt et al. (2000) matched two sets of disyllabic words for number of phonemes, but different spoken durations. This was measured by recording and timing a number of different subjects reading the words aloud. The words were recalled verbally or by picture pointing. A number of different experiments, with adults, resulted in the finding that significantly more of the words with a longer spoken duration were recalled than words with shorter durations. This is the opposite to what would be predicted by the traditional interpretation of word length effects reflecting effects of spoken durations. Although why the words with shorter durations were more difficult to recall is not clear, given that they contained the same number of phonemes.

Another approach to this issue was taken by Service (1998) who contrasted recall of three sets of stimuli. Non-words based on Finnish phonology were created. A non-word (e.g. /tepa/) was matched with: i) a non-word that contained the same phonemes, but with some sounds lengthened e.g. / te:p:a/; ii) a non-word that contained more phonemes, e.g. /tiempa/. There was no significant difference in recalling a list of non-words with lengthened phonemes, i.e. of longer spoken duration, rather than non-words with shorter phonemes. There was a significant effect on span in recalling the words with more phonemes, i.e. the more phonologically complex words.

A number of studies have now challenged the traditional view that word length effects are the result of spoken durations. It may be that at least some of the word length effect is related to the amount of phonological material to be recalled, rather than how long it takes to say the material. As discussed in Chapter 2, Cowan et al. (1992) and Henry (1991b) suggest that word length effects may arise at spoken recall. It would be interesting to compare spoken and picture-pointing recall of stimuli containing different amounts of phonological material to see if there is more effect of phonological complexity on spoken recall than on non-spoken recall.

5.3 RATIONALE FOR THIS EXPERIMENT

The experiment presented here was designed to compare performance on STM tasks using different combinations of input and output mechanisms. This would allow the different speech processing requirements of these STM tasks to be considered. Sets of stimuli were used that were matched for spoken duration but varied for number of phonemes in the word. This was to allow a different interpretation of the word length effect to be evaluated, i.e. that it arises from the amount of phonological material to be recalled, rather than from spoken duration.

5.3.i Predictions

The 3 STM tasks have different speech processing requirements. It is hypothesised that speech processing requirements will affect STM recall, so performance will differ on the STM tasks that involve different input and response mechanisms.

STM capacity may be affected by the amount of phonological information to be recalled, rather than by the spoken duration of the stimuli. It is hypothesised that phonologically simple word lists will be easier to recall than phonologically complex word lists that are matched for spoken duration.

It has been suggested that word length effects might arise at the level of spoken recall rather than within the sub-vocal rehearsal process. If the phonological complexity of the stimuli is responsible for the word length effect, and the word length effect arises at spoken output, then there will be a greater effect of complexity on spoken recall than on picture pointing recall.

5.4 METHOD

5.4.i Experimental Design

This experiment investigated within-subject differences in performance on 3 different STM tasks, with 2 conditions that differed in degree of phonological complexity.

5.4.ii Participants

Twenty-two children aged between 4;06 and 5;00 years at the start of the study were recruited from 3 main-stream primary schools. Parents signed a consent form to allow their child to participate. Criteria for selection were:

i) no history of speech and language difficulties or of significant hearing loss

ii) considered by their teacher to be within the average range, with no evidence of any general or specific learning difficulty

iii) English as a first language

iv) no significant medical or neurological condition

The use of a range of speech and language measures in the whole test battery used (see Chapter 6) allowed for children to be screened for speech and language difficulties. This resulted in two children being rejected from this participant group.

The participants were first tested when aged between 4;06 and 5;00 years (T1). They were tested again on a similar test battery approximately one year later, when aged between 5;06 and 6;00 years (T2).

5.4.iii Task Materials and Procedures

Tasks

Measurements of STM often involve the use of a procedure of presenting increasing numbers of items for recall, until the child is unable to remember all the items in the list. The longest list length recalled is then referred to as the span. An alternative procedure is to use a fixed list where the same number of stimuli are presented. A fixed list length STM procedure was selected for two reasons: i) to keep testing times within a reasonable period for young children; ii) as criteria for selection of stimuli was very stringent, the generation of additional stimuli needed for an increasing span procedure would have made it difficult to maintain this stringency. The frequent repetition of a small number of stimuli within an increasing span procedure might have led to familiarity being a confounding variable.

Lovatt et al (2000) suggest that use of an increasing span paradigm and a fixed list paradigm give the same pattern of results, in a study of STM in adults. However, the use of a fixed list length produced more consistent results than an increasing span procedure, and was, therefore, considered

to be a more sensitive measure for young children (Hitch et al., 1989a). An increasing span procedure allows more accurate comparison across different age – groups, where use of a fixed list length might result in ceiling or floor effects in the oldest or the youngest children. This is not a requirement in the present study. Cowan, Saults, Nugent and Elliott (1999) found that whilst scores of number of items correct in serial order was sensitive to list length, scores of number of items correct, regardless of serial order, was independent of list length and increased with age. These authors suggested that list length does not have to be adjusted to match participants STM span. Therefore, as long as the fixed list presented is above the span of the participants, scoring for number of items correct will provide a sensitive measure. Fixed list lengths of 4 items have been used with children aged 4 years (Hulme, 1987), aged 5-8 years (Palmer, 2000,) and with 5 year-olds (Hitch et al., 1989c, Longoni & Scalisi, 1994).

SISO (Spoken Input - Spoken Output) task.

The stimuli were presented on a pre-recorded tape. No repetitions were allowed. The child was asked to listen to the words and to say them. There were two practice items, the first containing 3 words, the second containing 4 words, during which feedback was given to encourage the child to recall as many of the words as possible. The child's responses to each item were tape recorded and transcribed. Recordings were later checked to ensure accuracy of transcription.

SIPO (Spoken Input – Picture-pointing Output) task.

The child was asked to listen to the word lists, presented on a pre-recorded tape. No repetition of items was allowed. When all 4 or 5 words had been presented, a card containing the 6 or 7 pictures was placed in front of the

child, for him to point to the pictures representing the words heard. There were 2 practise items during which feedback was given to encourage the child to point to the pictures named. The test items were then presented and the child's responses noted.

PISO (Picture Input -Spoken Output)

There were 4 or 5 pictures per list presented one at a time, and each turned over by the tester at a rate of 1 per 2 seconds. The 2 seconds was judged by using a digital watch that displayed seconds. The child was asked to remember the pictures and tell the tester which pictures he had seen. There were 2 practice lists during which feedback was given. Responses were tape-recorded and transcribed. Recordings were later checked to ensure accuracy of transcription.

Experimental Stimuli

Several factors were considered in the selection of words for use in the fixed list lengths to be presented. Word frequency measures were not considered reliable for use with young, pre-reading children as these are based on written frequency (Carroll, Davies & Richman, 1971). Spoken word frequency measures (e.g. Brown, 1984) are based on adult derived data. Age of acquisition (AoA) measures relate to the age at which children first learn a word. These have been calculated from adult ratings of when a word was first learned (Gilhooly & Logie, 1980, Carroll & White, 1973). AoA has been found to be a better predictor of performance on object naming than word frequency, in adults (Brown & Watson, 1987, Morrison, Ellis & Quinlan, 1992).Walley and Metsala (1992) found children to be more likely to recognise words with earlier AoA, and that children's ratings of AoA of words was the same as adults. Morrison,

Chappell and Ellis (1997) found significant correlations between rated AoA and objective AoA as measured in children. They conclude that "adult ratings provide a reliable and valid measure of real word learning age" (p. 528).

As this study involved the testing of young children, AoA was considered to be the most important factor in stimuli selection, and word frequency was not controlled for. Gilhooly and Logie (1980) (and Carroll & White, 1973) rate words on a scale from 1-7. Point 1 corresponds to an AoA of 0-2 years, point 2 to an AoA of 3-4 years, and so on.

The stimuli for the memory tasks at T1 consisted of 12 words with a phonologically simple structure and 12 words with a phonologically complex structure. Words were selected according to the following criteria:

i) Age of acquisition by 4 years, i.e. AoA rating of 1 or 2 (Gilhooly & Logie, 1980, Carroll & White, 1973).

ii) Noun, able to be illustrated by colour photograph.

iii) Not included in stimuli lists for experimental speech processing tasks, used in further experiments, to be reported later (see Chapter 6).

iii) Single syllable, containing only 'pure' vowels (i.e. not dipthongs); and either phonologically simple in structure (with no clusters present), i.e. CVC, or phonologically complex in structure (with one 2 element consonant cluster present in each word), i.e. CCVC or CVCC.

A set of words matching these criteria were recorded from live voice, onto a Kay DSP Sonograph, Model 5500. Waveform analyses of the speech

signal were used to time 3 live spoken durations of each word. A mean measure of time for spoken duration was calculated for each word. Visual inspection of the mean durations was used to prepare a set of 12 phonologically simple words, and a corresponding set of 12 phonologically complex words. The words across the two lists were paired to match as closely as possible on mean spoken durations. (see Table 5.1). An independent samples t test showed no significant difference between mean spoken durations for simple and complex word lists, $t_{(22)}$ =.088 (p=.993). The mean of the differences between shortest and the longest duration of the live utterances of each word was larger than the mean of differences in timings between each complex word and its matched simple word. This suggests that any difference between a complex and a simple word was no greater than the difference that would be found in duration when saying the same word more than once. No significant difference was found in age of acquisition ratings for the simple and complex word lists ($F_{(1,23)}$ =.87, p=.361).

The items from each of the 2 stimuli lists were grouped into three sets of 4 stimuli. The following criteria were used:

i) Absence of phonological similarity between items, for example words with the same onsets or vowels were not placed in the same set.

ii) The total duration of each set of 4 items to be as close as possible.

iii) The matched pairings between words were maintained in the production of the sets, so that set A contained 4 simple words and the 4 complex words matched on spoken duration. (see Table 5.1).

The order of the words in each set were varied to produce 3 different word orders for the 3 STM tasks. The matched pairs occurred in the same place

in each string so that the first item in the string for simple words was of similar duration to the first item in the string for complex words etc. (see Table 5.1).

Table 5.1: Stimuli sets for T1 tasks.

Set	Simple word	Mean duration in secs	(s.d.)	Complex word	Mean duration in secs	(s.d.)
A	Tap	.5229	(.02)	Clock	.5276	(.03)
	Bus	.5010	(.01)	Bread	.4953	(.01)
	Sock	.6364	(.03)	Spoon	.6620	(.05)
	Leaf	.6068	(.04)	Crab	.5547	(.02)
Total mean duration		2.2671			2.2396	
B	Cup	.4719	(.01)	Drum	.4938	(.03)
	Ring	.5448	(.01)	Frog	.5500	(.03)
	Shop	.6203	(.02)	Tent	.6391	(.04)
	Horse	.6073	(.03)	Bridge	.5521	(.02)
Total mean duration		2.2443			2.2350	
C	Girl	.5016	(.02)	Plug	.5182	(.03)
	Pig	.4406	(.02)	Brick	.4677	(.02)
	Fork	.6604	(.03)	Box	.6765	(.02)
	Cheese	.7291	(.06)	Flag	.6859	(.01)
Total mean duration		2.3317			2.3483	

At T2, as the children were one year older, and some had scored highly on the tasks presented at T1, additional items were generated for each word list, so that the fixed list length was 5 items. The extra stimuli were generated using the same criteria as for T1 stimuli. As before, there was no

significant difference in mean spoken durations for the phonologically simple and the phonologically complex stimuli, $t_{(28)} = -.075$, $p = .941$. Stimuli were allocated to fixed lists of 5 words in the same way as before (see Table 5.2).

Table 5.2: Stimuli sets for T2 tasks

Set	Simple word	Mean duration in secs	(s.d.)	Complex word	Mean duration in secs	(s.d.)
A	Cup	.4719	(.01)	Drum	.4938	(.03)
	Ring	.5448	(.01)	Fox	.5344	(.02)
	Cheese	.7291	(.06)	Sweet	.6927	(.03)
	Girl	.5016	(.02)	Plug	.5182	(.03)
	Horse	.6073	(.03)	Bridge	.5521	(.02)
Total mean duration		2.8547			2.7912	
B	Knife	.5604	(.03)	Frog	.5500	(.03)
	Bus	.5010	(.01)	Bread	.4953	(.01)
	Shell	.6453	(.02)	Box	.6765	(.02)
	Sock	.6364	(.03)	Spoon	.6620	(.05)
	Leaf	.6068	(.03)	Crab	.5547	(.02)
Total mean duration		2.9499			2.9385	
C	Shop	.6203	(.02)	Swing	.6427	(.02)
	Church	.6146	(.02)	Tent	.6391	(.04)
	Pig	.4406	(.02)	Brick	.4677	(.02)
	Fork	.6604	(.03)	Flag	.6859	(.01)
	Tap	.5229	(.02)	Clock	.5276	(.03)
Total mean duration		2.8588			2.9630	

Materials

For SISO and SIPO presentations tape-recordings were made of the stimuli. Each list was recorded with a 1 second interval between words. Photographs were prepared of all the objects portraying each stimulus word. Photographs were examined to ensure that they were not visually similar to others in the same set. This was to ensure that visual similarity effects would not be a confounding variable in performance. The photographs were mounted singly onto card for the PISO task. For the SIPO task, sets of 6 photographs were mounted together onto large card. These were the 4 required stimuli and 2 distractors selected randomly from the other words within T1 lists. For T2 lists, 7 photographs were selected for each response card, the 5 target items and 2 distractor pictures randomly selected from the other items.

Scoring

The total number of correct responses to each list given by each child were counted, regardless of order of response. Spoken responses were counted as correct if the word was recognisable as the target, allowing for phonological or articulatory immaturities. For the PISO task, if the child used a label that was semantically appropriate to the picture, and, therefore, suggested the item had been recalled, e.g. 'van' instead of 'bus', then this was also scored as correct.

5.4.iv Experimental Procedure

The STM tasks were part of a larger testing battery (see Chapter 6) that was presented over 3 separate testing sessions. The order of tasks was systematically varied over 4 different orders of presentation. The STM tasks were carried out, along with a number of other tasks, in two testing

sessions. The children were all tested in their school environment, in an area away from, and quieter than, their classroom. Immediately before the first STM task was presented, the participants were asked to name each of the stimulus photographs, as a vocabulary check. If the child was unsure of an item name, this was supplied and repeated, and the child encouraged to use the label.

5.5 RESULTS

5.5.i Pilot Study

A small pilot study had been carried out with 11 children within the age-group specified. The scores on the 3 STM tasks were normally distributed. No ceiling or floor effects were evident. Analysis of that data showed a significant difference in performance between tasks, and a significant effect of phonological complexity on performance (see Appendix 7). There was no effect of order of tasks on performance, suggesting that any practice effects are minimal. The findings of the pilot study suggested that the tasks and the stimuli were suitable for the purpose and age-group for which they were designed.

5.5.ii Task and Complexity effects at T1

Means and standard deviations were calculated for lists of phonologically simple stimuli and lists of phonologically complex stimuli for each of the 3 STM tasks (see Table 5.3) At T1 scores were normally distributed and data showed homogeneity of variance. A repeated measures analysis of variance was, therefore, carried out on the data (see Table 5.4).

Table 5.3: Mean (s.d.) number of simple and complex items correct for STM tasks at T1 and T2.

	T1	T2
	No. of items = 12	**No. of items = 15**
SISO simple	7.76 (2.76)	8.00 (2.90)
SISO complex	7.14 (2.26)	6.67 (2.33)
SIPO simple	9.57 (1.40)	12.29 (1.42)
SIPO complex	9.76 (1.37)	11.52 (1.47)
PISO simple	6.43 (2.11)	8.10 (2.47)
PISO complex	5.48 (1.83)	7.29 (1.59)

Table 5.4: ANOVA table of Task x Complexity at T1

Source of variation	SS	DF	MS	F	Sig. of F
Error	100.048	40	2.501		
Task	293.286	2	146.643	58.629	<.001
Error	38.159	20	1.908		
Complexity	6.675	1	6.675	3.498	.076
Task X Complexity	7.254	2	3.627	2.218	.122

There was a significant effect of task paradigm ($F_{(2,40)}$ 58.63, p <.001). The main effect of complexity approached significance (($F_{(1,20)}$ 3.498, p = .076). There was no significant interaction between task and complexity. There is, usually, a large amount of individual variation in the performance

of young children on tasks like these. For example, attention can fluctuate and affect performance quite markedly. As the effect of complexity approached significance, the data was examined to see if any individual variation appeared to be affecting the findings. Visual inspection of data showed that the scores of one subject displayed an uncharacteristic profile of performance, with a large negative effect of complexity on the SISO task. The analysis of variance was repeated, omitting data from this subject (see Table 5.5). There was a significant effect of task paradigm ($F_{(2,38)}$ 64.32, $p < .001$) and of complexity (($F_{(1,19)}$ 5.211, $p < .05$). There was no significant interaction between task and complexity.

Table 5.5: ANOVA table of Task x Complexity at T1, (data from one subject omitted).

Source of variation	**SS**	**DF**	**MS**	**F**	**Sig. of F**
Error	86.883	38	2.286		
Task	294.117	2	147.058	64.319	<.001
Error	33.092	19	1.742		
Complexity	9.075	1	9.075	5.211	.034
Task X Complexity	8.450	2	4.225	2.980	.063

Main effects of task differences were explored using paired sample 't' tests. Performance on SIPO was significantly better than performance on SISO ($t_{(20)}$=7.130, p<.001) and on PISO ($t_{(20)}$ = 11.419, p<.001). Performance on SISO was significantly better than performance on PISO ($t_{(20)}$=4.479, p<.001). Inspection of the means showed that the main effect

of complexity arose because scores on the phonologically simple word lists were higher than on the phonologically complex lists.

At T1, there were significant differences in performance across the 3 STM tasks presented. Scores were highest on SIPO and lowest on PISO. There was a significant effect of complexity, with fewer items in the phonologically complex lists recalled.

5.5.iii Task and Complexity at T2

At T2 scores were normally distributed and data showed homogeneity of variance. A repeated measures analysis of variance was, therefore, carried out on the data (see Table 5.6). Analysis of variance of performance on the 3 tasks, SISO, SIPO, and PISO, at T2, showed significant effects of task ($F_{(2,40)}$ 63.633, $p < .001$), and of complexity ($F_{(1,20)}$ 12.665, $p = .002$). There was no significant interaction between task and complexity.

Table 5.6: ANOVA table of Task x Complexity at T2

Source of variation	SS	DF	MS	F	Sig. of F
Error	170.667	40	4.267		
Task	543.000	2	271.500	63.633	<.001
Error	46.635	20	2.332		
Complexity	29.532	1	29.532	12.665	.002
Task X Complexity	2.111	2	1.056	.458	.636

The significant main effect of task was explored using paired sample t tests. Performance on SIPO was significantly better than performance on SISO(($t_{(20)}$ =8.547, p <.000) and on PISO ($t_{(20)}$=11.722, p <.001). However, there was no significant difference between SISO and PISO performance ($t_{(20)}$ = .810, p=.427). Visual inspection of the means suggested that main effects of complexity were the result of better recall of phonologically simple word-lists than of phonologically complex lists.

5.5.iv Effects of phonological complexity in different recall conditions

There was no significant interaction between task and complexity. Visual inspection of the mean number of items correct to each task (see Table 5.3) shows very little difference between phonologically simple and complex lists on the SIPO task. There is an observable difference between recall of simple and complex lists for the PISO task at T1 and at T2, with a trend for more items in the simple lists to be recalled. For performance on the SISO task, there is less difference in recall between simple and complex lists at T1, and a greater difference in recall at T2.

At T1 there is a trend for a greater effect of complexity on recall in the PISO task, than for the SISO task. However, at T2 there is a trend for a greater effect of complexity on recall in the SISO task, than the PISO task.

5.6 DISCUSSION

5.6.i Differences in Performance between STM Task Paradigms

The finding of significant main effects of task at both T1 and T2 confirms the hypothesis that there will be differential performance on STM tasks that use different input and output mechanisms. This is in contrast to Adams and Gathercole (2000) who found that there was no difference in recall for STM tasks with spoken presentation and spoken or picture-pointing recall. But Lovatt et al. (2000) found better recall in the picture-pointing response condition than in the spoken response for adults.

Results reported here suggest that at age 4-5 years, if the list presentation is verbal, children find it easier to point to pictures in response rather than to say the words. Children find it more difficult to verbally recall lists presented pictorially, than lists presented verbally. At age 5-6 years, if the list presentation is verbal, children still find it easier to point to pictures in response rather than to say the words. However, they no longer find it more difficult to recall lists presented pictorially rather than verbally.

There are a number of reasons why children may perform better on the task with spoken presentation and picture-pointing recall (SIPO). There is a greater possibility of getting some or all of the items correct by chance in the SIPO task, in that 4 out of 6 or, 5 out of 7 pictures presented are correct for each list. If a child is aware of how many pictures they should select, and then randomly select that number of pictures, they have quite a high chance of selecting some or all of the correct pictures. There would have been less of a chance element if scoring was based on ordered recall, as was the case in Adams and Gathercole's (2000) study. Secondly, the

pictures may well act as a reminder sufficient to activate a fading memory trace, and this cue is not present in the spoken recall condition.

The difference in performance between the SISO and the SIPO tasks requires some consideration. Both these tasks used a spoken presentation, so the speech input requirements were the same, it is the recall mechanism that differs. Therefore, from a speech processing perspective, the difference in task performance suggests that speech output processing might constrain STM task performance in some way. This will be discussed more fully in Section 5.6.iii. However, the findings must be considered in the light of the other advantages of the picture-pointing response proposed above. A more stringent test of whether or not the poorer performance on spoken recall was due to speech output constraints might include scoring for order of recall, and / or presenting more distracter items for the picture-pointing response.

The relationship between performance on the two tasks with spoken recall changes over time. At age 4-5 years children recall more words with spoken presentation, than with pictorial presentation, however by the age of 5-6 years, there is no difference in performance for these two presentations. One factor to consider, is that of phonological recoding of picture material. As discussed in the literature review, there is some debate about the age at which children use the phonological loop to maintain picture material in STM. One interpretation of these results is that at age 4-5 years, the children are using different strategies to recall spoken and pictorial stimuli, but by 5-6 years of age, a similar strategy is being used to recall both types of material and so performance is much more similar. This suggests phonological recoding of picture material is occurring by the

age of 6 years, which is earlier than suggested by Hitch et al. (1989a, 1989c), but in line with findings of Hulme et al. (1986) and Hitch et al. (1988)

In this study the children were not prevented from naming the pictures as they were presented, and in this respect was unlike the studies of Hitch et al. (1989a, 1989c) and Longoni and Scalisi (1994). Observation was that some children did name some or all of the pictures as they were presented. Whether or not children chose to do this might reflect individual differences in processing preferences and / or in developmental level. Some of the children may have been ready to phonologically recode the picture material, and naming the pictures supported this process. Palmer (2000) reports individuals differences in age at which phonological re-coding takes place, from the age of 5 years in some children. Another factor to consider is that the response mechanism was spoken. Although Hitch et al. (1988) and Longoni and Scalisi (1994) argue that picture material may not be recoded until the point of spoken output, in younger children, it is possible that the children recoded the pictures at input, recognising that this form would be needed for output. One way to address this would be in a study comparing picture presentation tasks with a spoken response and with a picture pointing response, to see if a spoken response was more likely to trigger phonological recoding and thus phonological similarity or word length effects.

Better performance for spoken rather than picture-pointing presentation at T1, and the lack of a difference between spoken and pictorial presentation at T2, suggests that speech input processing skills may not play an important role in STM task performance.

5.6.ii Phonological Complexity Effects

In the body of research, word length effects have been considered to reflect the effect on recall of the spoken durations of the material (Baddeley et al., 1975). In the present study lists of words that differed on the number of phonemes were carefully matched for spoken duration. Significant differences were found in recall of the different word-lists. More words containing fewer phonemes were recalled than words with more phonemes. This suggests that at least some of the word length effect may arise as a function of differing amounts of phonological information within the words to be recalled, rather than solely from spoken durations. This is in accord with findings by Caplan et al. (1992), Service (1998) and Lovatt et al. (2000).

On this view, recall is affected by the amount of phonological information to be recalled. This may mean that the phonological store and the sub-vocal rehearsal process are limited by the number of 'slots' available in storage and / or in rehearsal, rather than being constrained by the time available to articulate the stimuli. It may be that STM capacity reflects an interaction between the amount of phonological information to be recalled and its spoken duration. Further investigation is warranted to explore the different interpretations. Studies could usefully contrast word lists in terms of the number of phonemes, the number of syllables and the spoken duration of stimuli. For example, it would be possible to construct word lists in which stimuli contained the same number of phonemes, but differed in number of syllables. This would be an important contrast to make as the word-length effect has traditionally been observed in the use of lists of stimuli that vary in number of syllables, rather than number of phonemes. The nature of the phonological complexity effect is not clear-

cut. It does show that there is differential performance on lists containing stimuli with different numbers of phonemes but matched on spoken duration.

5.6.iii Effects of Complexity in Spoken and Non-spoken Recall

Another interpretation of reduced recall of the phonologically more complex stimuli, which all contained clusters, is of an output constraint. Cowan et al. (1992) have argued that word length effects arise at output in terms of spoken duration at output. Caplan et al. (1992) suggest that word length effects are determined by phonological structure arising at the level of speech output processing. However, they did not find a significant difficulty with recall of words containing clusters (CCV) as against other words not containing clusters (CVC). Gathercole and Baddeley (1989) and Bishop et al. (1996) suggest that significant effects of consonant clusters on NWR performance reflect articulatory demands. If phonological complexity effects are the result of spoken output constraints then one would expect this effect to be greater for tasks involving spoken output and not the task without spoken output. As articulatory skills are less mature in younger children, we would expect to find a greater effect at a younger age, than at an older age.

In this study there was an observable (but non-significant) trend for a greater effect of phonological complexity on spoken (PISO and SISO) rather than picture pointing (SIPO) recall at T1 and at T2. Visual examination of the complexity effect suggests that it is greater at T2 (particularly for SISO), and so may not be related to the maturity of articulatory skills. This suggests that effects of clusters on NWR accuracy, interpreted by Gathercole and Baddeley (1989) and Bishop et al. (1996) to

indicate articulatory demands, should be reconsidered. It may be that these effects arise from the increase in number of phonological units within the non-words containing clusters, that need to be discriminated and maintained in STM. However, it should be noted that in this study scoring did not take account of pronunciation, in that if children misarticulated the clusters, they would still be credited with recall of that item. This should minimise any effect that articulatory skill has on recall of lists of phonologically complex words. In the studies of NWR referred to above, scoring would account for articulation of each part of the clusters.

The observable trend across the task conditions, in which the recall mechanism differs, suggests that the effect of phonological complexity is greater for spoken output. This supports hypotheses from Cowan et al. (1992) and Henry (1991b) who suggest that word length effects may be a function of spoken recall. If effects of phonological complexity and word length are located in speech output, this may not be the result of articulatory skill at a level of motor execution, but rather at some more central level of speech output processing. It is unlikely that the word length effect arises from spoken duration at output, if an effect of phonological complexity is observable, where stimuli have been matched for duration. Further studies that use stimuli that reflect differences in phonological complexity and word length that are used across STM tasks with different presentation and response modes may help to clarify the nature of both these effects.

5.7 CONCLUSION

This experiment has found differential performance across 3 different STM task paradigms. The speech processing demands of the STM tasks were manipulated to allow comparison of tasks with and without speech input and speech output. Recall was affected by the speech processing demands, and was reduced when spoken output was required.

The research literature has cast some doubt over the traditional interpretation of the word length effect. This experiment confirms that the word length effect may, in part, be a function of the amount of phonological material to be recalled, rather than its articulatory duration.

CHAPTER 6
EXPERIMENT 4: A LONGITUDINAL STUDY OF SPEECH PROCESSING, SHORT TERM MEMORY AND LANGUAGE DEVELOPMENT

6.1. INTRODUCTION TO CHAPTER

Strong relationships have been found between short-term memory (STM), speech processing and language development (see Chapters 1 and 2 for a review). However, there is still much debate about the nature of these relationships. Experiment 1 (in Chapter 3) explored experimental measures of speech production and auditory discrimination and relationships between performance on different speech processing tasks. Chapter 4 considered the role of speech processing in non-word repetition (NWR), a task that has been used to measure phonological short-term memory (PSTM). Experiment 3 (in Chapter 5) examined effects of different task paradigms and stimuli on STM scores.

Experiment 4 will be presented in this chapter. This experiment brings together performance on speech processing and STM tasks with measures of language development in order to examine relationships between these different functions. These relationships are not usually evaluated within the same study, and few studies are longitudinal in design. This experiment uniquely combines measures of STM, auditory discrimination and speech production with multiple measures of language development within a longitudinal study. Potential relationships between NWR and speech processing, STM and language will also be considered. As this is a

longitudinal study there is, therefore, an opportunity to compare performance across time points and to examine predictive relationships.

6.2 INTRODUCTION TO EXPERIMENT

6.2.i Relationships between NWR and STM and Speech and Language Skills

The use of NWR as a speech processing task and as a STM measure has already been discussed and investigated in Chapter 4. The finding of the experiment presented in Chapter 4 was that speech production and auditory discrimination skills were significantly correlated with accuracy of NWR. Other studies have found significant relationships between NWR and STM task performance (e.g. Gathercole, 1995a, Metsala, 1999).

NWR has been found to be more closely related to word repetition than to digit span in 2-3 year-old children (Gathercole & Adams, 1993), and more strongly correlated with auditory discrimination than with digit span in 4 year-old children (Gathercole et al., 1999). This same and different auditory discrimination task used lists of non-words in an increasing span procedure and was designed to tap PSTM without requiring any speech output. The use of non-word material might result in this task having a closer relationship with NWR, than with digit span, which uses familiar stimuli. However, Metsala (1999) found NWR to be more strongly correlated with digit span and word span measures than with performance on a range of phonological awareness tasks in 4 – 5 year-old children. Metsala (1999) also found that STM contributed unique variance to NWR in 4-5 year-old children, after age and phonological awareness skills had been accounted for, but not in 3-4 year-old children. The relationships

between NWR and STM and speech processing skills are not clear cut and will be explored further in this experiment.

There is evidence for significant relationships between NWR and vocabulary (Gathercole et al., 1992, Gathercole & Adams, 1993, Bowey, 1996) and grammatical development (Adams & Gathercole, 1995, 1996, Bowey, 1996). It is not clear whether these relationships reflect the STM skills that may contribute to both NWR and to language development, or whether the relationship is unique to NWR.

Gathercole and Adams (1993) found that receptive vocabulary was significantly correlated with NWR in 2-3 year-old children, but not with digit span. However, the significant relationship between receptive vocabulary and NWR was not found when a sub-set of this group were analysed further (Adams & Gathercole, 1995). At age 4 years, expressive vocabulary was more strongly significantly correlated with NWR than with digit span (Gathercole & Adams, 1994), and receptive vocabulary was significantly correlated with NWR but not with digit span. At age 5 years, expressive vocabulary was significantly correlated with NWR but not with digit span. The expressive vocabulary measure used here was a word definitions task, which is very taxing of expressive language generally, rather than a measure of how many words the child uses (Gathercole & Adams, 1994). Adams and Gathercole (1996) also found that expressive language skill was more strongly correlated with NWR than with either digit or word span, when the language measure was the Renfrew Bus Story (Renfrew, 1991). NWR contributed additional significant variance in expressive language scores after age, non-verbal and vocabulary knowledge was accounted for, but the span measure did not. These

findings all indicate NWR may play a greater role in the development of language skills than STM.

Avons et al. (1998) reported that word span accounted for a larger proportion of significant variation (19%) in receptive vocabulary that NWR (13%). Bowey (1996) confirms that STM may play a greater role in language development than NWR. NWR did not account for further significant variability in receptive vocabulary and grammar after age, non-verbal scores, phonological awareness skills and digit span scores were entered into a multiple regression analysis. Digit span did account for further significant variation after NWR was entered.

However, not all studies confirm a significant relationship between NWR and language skills. Edwards and Lahey (1998) found that receptive vocabulary was not significantly correlated with NWR in normal children (using the long form of Peabody Picture Vocabulary Test). They suggest that their findings may differ from those of Gathercole and Adams' series of studies because Edwards and Lahey's non-word stimuli did not contain any words or morphological endings within the stimuli. The issues that have been considered in the selection of stimuli for NWR, including wordlikeness effects, have been previously discussed in Chapter 4. One hypothesis is that STM has more impact on the repetition of less word-like non-words and that existing lexical knowledge is implicated to a greater degree in repetition of more word-like non-words (Gathercole, 1995b). If this is so, then stronger relationships would be expected between repetition of more word-like non-words and vocabulary. Bishop et al. (1996) found that for a mixed group of language impaired and normally developing children, NWR was not significantly correlated with performance on a

number of language measures, including receptive grammar and word finding.

Some studies show that language development is more strongly associated with STM measures than with NWR. Gathercole et al. (1999) found that performance on a word definitions task was more strongly correlated with digit span than with NWR in 4 year-olds. Both NWR and digit span were significantly correlated with some measures of expressive language encompassing vocabulary and grammar, in 3 year-old children (Adams & Gathercole, 1995). Some of the language measures were more strongly correlated with NWR and other measures were more strongly correlated with digit span, neither task was consistently more strongly correlated with the different language measures than the other. Metsala (1999) found NWR and digit and word span to be correlated with receptive vocabulary to a very similar degree, in 4-5 year-olds. Blake et al. (1994) found that word span significantly predicted mean length of utterance in the spontaneous language of 2-3 year-old children, in a multiple regression analysis.

6.2.ii The Role of Speech Processing and Language Development in STM Capacity

Chapter 2 presented research findings that suggested a range of speech processing skills are implicated in STM performance. These include significant relationships between STM span and speech rate (Hulme et al., 1984), and time taken to repeat words (Henry & Millar, 1991). Such studies have tended to focus on measures of the speed of speech processing rather than the accuracy of processing.

However, some studies do not confirm the relationship between speech rate and span. Speech rate was not significantly correlated with span when the speech rate measure was based on repetition of a single word in children aged 5-11 years (Henry, 1994). In Gathercole et al.'s (1999) study, digit span at 4 years of age was not significantly correlated with speech rate measured one year later. Gathercole and Adams (1993) found digit span was not significantly correlated with speech rate in 2-3 year-old children. Subsequently, Gathercole and Adams (1994) found that speech rate was not significantly correlated with digit span at age 4 years, or with word span at age 5 years, but was significantly correlated with digit span at age 5 years.

Word identification time (measured as time taken to repeat words) and speech rate were both significantly correlated with word span (Henry & Millar, 1991). This was in contrast to the finding of Hitch et al. (1989b) that speech rate was a significant predictor of word span in 8 and 11 year-olds, but identification time was not. Speech rate and word identification time measures may reflect global processing speed, as discussed in Chapter 2. Cowan and Kail (1996) argued that processing speeds can affect STM development.

Some researchers have examined relationships between STM and the accuracy of speech processing. Gathercole et al. (1999) reported that performance on an auditory discrimination task (same / different judgement of strings of non-words) was significantly correlated with digit span. However, this was a task with a heavy STM loading, so such a relationship is, perhaps, unsurprising. Performance on tasks requiring the auditory discrimination of one or two syllable stimuli was significantly

correlated with digit span in Watson and Miller's (1993) study of young adults. Elliott, Hammer and Scholl (1989) also reported that scores on same / different discrimination of pairs of syllables was significantly correlated with digit span in children aged 6 to 11 years old.

Other studies have found relationships between accuracy of speech output processing and STM. A significant correlation was found between digit span and accuracy of word repetition in 3 year-olds (Gathercole & Adams, 1993). Accuracy of word and non-word repetition were also found to be significantly correlated with speech rate. It is possible that speech rate is related to accuracy of speech processing skills. However, focusing on relationships between timed elements of speech processing and STM may obscure important information about the relationship between accuracy of speech processing and STM.

As discussed in Chapter 1, the relationship between language development and STM has been explored. Robust findings of effects of word familiarity on span performance (Roodenrys et al., 1994, Henry, 1994) may reflect ways in which levels of vocabulary knowledge affect STM capacity. A number of studies have been presented in Section 6.2.i that have found significant relationships between STM measures, such as word span and digit span and various language measures (Adams & Gathercole, 1995, Bowey, 1996, Metsala, 1999, Gathercole et al., 1999).

If there is a causal direction in the relationship between speech processing and / or language and STM, this has not yet been clearly established. Most of the reported relationships reflect correlational associations, which do not determine any cause and effect that might exist between two skills.

For example, it is possible that level of language development determines STM skills. This argument would account for van der Lely and Howard's (1993) finding that children with SLI showed STM performance that was equivalent to that of younger children of the same language level. One way to address these issues is to use a longitudinal experimental design, in which measures taken at one point in time can be compared to measures taken at a later stage of development.

6.2.iii The Role of Speech Processing and STM Capacity in Language Development

There is little direct research to show whether speech production and auditory discrimination skills play a part in the development of language skills. Elliott et al. (1989) found that auditory discrimination skills, as measured by same / different discrimination of pairs of syllables, was significantly correlated with receptive vocabulary and verbal comprehension in school-children. It is widely accepted that children with hearing impairments will often have difficulty in developing spoken language, again implicating auditory processing.

Some researchers have argued that STM skills play a major role in the development of language (e.g. Baddeley et al., 1998), although a number of these studies rely on NWR as the STM measure. This issue has already been more fully discussed in Chapter 1. This study attempts to consider the role of STM in language development, using more traditional measures such as word span. STM has been found to be related to aspects of language development as already mentioned in Section 6.2.i.

Sentence repetition is widely used as a standardised measure of expressive language (e.g. Clinical Evaluation of Language Fundamentals, Semel, Wiig & Secord, 1987). This task would seem to be reliant on STM capacity. Indeed, Blake et al. (1994) reported a significant correlation between sentence repetition and word span in children aged 2-5 years. However, mean length of utterance was also significantly correlated with sentence repetition. It is possible that grammatical development will affect performance and that this is the justification in using this task as a test of expressive language. Bishop et al. (1996) found that performance on a receptive grammar measure was significantly correlated with performance on a sentence repetition task in a group of young people with and without language disorders. Bliss and Peterson (1973) investigated sentence repetition in a group of young children. The children made significantly more errors in repeating grammatically complex sentences than in repeating simpler sentences that were of the same length. Thus, implicating grammatical competence in performance on sentence repetition rather than STM.

6.3 RATIONALE FOR THIS EXPERIMENT

Many studies have independently examined the questions of relationships between STM, NWR, speech processing skills, processing speed and language development. Mixed findings have emerged, with different sets of tasks presented to groups of children of different ages. Most studies have focussed on only one or two aspects of these inter-relationships. The significant relationships between task performances that have been found are usually correlational, and within the same time frame. Conclusions that can be drawn about the nature of these relationships are, therefore, limited.

The aim of this experiment is to examine STM, NWR, speech processing, processing speed and language development in the same group of children. It is a longitudinal study with data collection at two time points, one year apart. This should allow the nature of relationships between skills in development to be considered.

6.3.i Predictions

This study employs a longitudinal design, so that concurrent and predictive relationships between performance on different tasks can be examined. Scores across time points can be compared, and this should allow analysis of which measures of performance at T1 best predict performance on another measure at T2. This may indicate the presence of causal relationships between skills in development. As this study was exploratory in nature, considering complex and possibly interactive relationships between speech processing, STM and language development, there are a number of research questions, each of which entails a number of hypotheses.

1. What is the relationship between NWR and STM and speech and language skills? The following hypotheses will be considered.

- Non-word repetition will be more strongly predicted by speech processing skills than by STM capacity.
- Language development will be more strongly predicted by NWR skills than by STM capacity.

2. What is the role of speech processing skills and language development in STM capacity? The following hypotheses will be considered.

- Speech production and auditory discrimination skills will predict STM capacity.
- Speech processing speeds will predict STM capacity.
- Language development will predict STM capacity.
- A consequent question from these hypotheses is: Which measures best predict STM development?

3. What is the role of speech processing skills and STM capacity in language development? The following hypotheses are considered.

- Speech production and auditory discrimination skills will predict language development.
- STM capacity will predict language development.
- STM capacity and grammatical knowledge will contribute equally to sentence repetition performance.
- A consequent question from these hypotheses is: Which measures best predict language development?

6.4 METHOD

6.4.i Experimental Design

This is a longitudinal study with data collected from one group of participants at 2 time points. There are no between-subject variables. There are a number of within subject variables. These are scores for each measure taken at T1 and at T2.

6.4.ii Participants

Some details of the 21 participants in this experiment, have previously been given in Chapter 5 (p. 182). They were aged between 4;06 and 5;00

years at the start of the study, and were developing normally. In addition to the selection criteria given in Chapter 5, two screening measures were used.

1. To demonstrate non-verbal skills were within the normal range, participants were required to achieve a scale score of 7 or more (i.e. to perform within normal limits) on the block design sub-test of the Wechsler Pre-school and Primary Scales of Intelligence (WPPSI, Wechsler, 1990).
2. To screen for hearing difficulties, participants were required to pass a binaural free-field screen with a criterion of 40 dB.

6.4.iii Experimental Procedure

Two screening measures were used. The block design sub-test of the WIPPSI was presented, the procedure given in the test manual was adhered to. A binaural free-field hearing screen was carried out using a Kamplex PA2. The stimulus noise was presented at a 40 dB level, 0.9 metres behind the child, at frequencies of 500, 1000, 2000 and 4000 Hz. The child was trained to put a toy into a box on hearing a sound..

The participants were tested at 2 time points. They were first seen at T1, when aged between 4;06 and 5;00 years. They were tested again at T2, one year later, when aged between 5;06 and 6;00 years. The time period between first and second testing was between 346 and 357 days. Each participant was seen for 4 separate sessions, of approximately half an hour. These sessions were arranged over a period of between 2 days and 20 days, with sessions falling within a 2 to 11 day period for most participants. The children were tested in their school setting in a quieter room or area away from their class-room. The tasks to be administered were carried out following one of four different orders of presentation.

6.4.iv Task Procedures and Materials

The test battery consisted of a range of standardised language assessment tasks, measures of speech processing skills, and STM.

Standardised Language Assessments

The following published, standardised assessments of language were used.

1. *Receptive vocabulary* was measured using the British Picture Vocabulary Scales (Dunn, Dunn, Whetton & Pintilie, 1982). A set of 4 pictures is presented to the child, a given stimulus word spoken and the child identifies the picture that matches the word heard. The procedure described in the test manual was followed.

2. *Expressive vocabulary* was measured using the Renfrew Word-finding Vocabulary Scales (Renfrew 1995). This is a single-word picture naming task. Black and white drawings are shown one at a time to the child for him / her to name. The procedure described in the test manual was followed.

3. *Receptive grammar* was measured using the Test of Reception of Grammar (Bishop 1989). Sets of 4 coloured drawings are shown to the child, a stimulus sentence is spoken, for the child to identify which picture best matches the meaning of the sentence heard. The procedure described in the test manual was followed.

4. *Expressive grammar* was measured using the Renfrew Action Picture Test (Renfrew 1989) ~~was used to measure~~. A series of coloured drawings are presented to the child and set questions asked. The child's answer is transcribed and scored according to given criteria. The procedure described in the test manual was followed. Two scores can be calculated. One gives an indication of the amount of information a child has been able

to convey in his spoken utterances, the second indicates the level of grammatical complexity used in the spoken utterances. Only the 'grammar' score is used in the analyses reported here.

Speech Processing Measures

Experimental tasks of auditory discrimination and speech production were presented to tap into different levels of speech processing, as outlined in Chapter 3. The procedures used have already been described in Chapter 3 (p. 105-112). Responses were scored as described in Chapter 3.

For Naming, Word Repetition, NWR, Auditory Discrimination Picture Task and ABX the stimuli lists used in Experiment 1 (see Chapter 3, p 106) were reduced from 60 to 24 items (see Appendix 8). Item analysis was carried out by Stackhouse, Nathan, Goulandris and Snowling (1999) and Nathan (in prep.) on the data collected in the experiment reported in Chapter 3, and on additional data from 10 children with speech and language difficulties. Items were selected that discriminated well between these two populations and between children of different ages using a difficulty index. Further details of this selection is available in Nathan (in prep).

For each task, the stimuli to be presented were listed in a random order and in two lists of equal length, list A and list B. As described in Chapter 3, p. 112, the presentation sequences of these lists ensured that children did not hear non-words immediately after their matched words.

Auditory Discrimination Tasks

Auditory Discrimination Picture Task

As described above, 24 stimuli were presented at T1 (see Appendix 9). At T2 an additional 12 multisyllabic items were included. These were selected from the original stimuli lists used in the experiment in Chapter 3. In all 4 orders of presentation, the auditory discrimination picture task followed the picture naming task, which acted as a vocabulary check. At T1, the task procedure described in Chapter 3, p. 106 was followed. At T2 the procedure was changed. Each picture was presented twice, and either the word or the non-word stimulus spoken. Order was randomised, so that the second presentation of the picture was not immediately after the first presentation. This different procedure had the advantage of facilitating attention control, the child was able to move more quickly onto a fresh picture, and redundant presentations of either the word or non-word stimuli were not required.

Same / Different Task (after Bridgeman & Snowling, 1988)

At T1 a reduced list of 10 word pairs and 10 non-word pairs was used (20 pairs in total), as compared with the stimuli used in the experiment in Chapter 3 (see Appendix 10). As with the reduced stimuli lists used in other tasks, these were selected following an item analysis by Nathan (in prep.). The stimuli were divided into two lists, each list containing 5 randomised non-word and 5 randomised word pairs. There were 4 same pairs and 6 different pairs in each list. At T2, the 9 word and non-word pairs used in the experiment in Chapter 3 that contained cluster changes were used (18 pairs in total) (see Appendix 10). These were selected because cluster distinctions were considered to be more difficult to discriminate (Bridgeman & Snowling, 1988), and, thus, may not be subject

to the ceiling effect that was found on performance on this task in the experiment reported in Chapter 3. The 18 pairs were presented in one word list, with 9 randomised non-word pairs presented before 9 randomised word pairs. There were 7 same pairs and 11 different pairs.

The procedure followed was the same as that described in Chapter 3 (p. 108), except for the practice items. For this experiment the child was first asked to listen and see if their own name was said in the same way or in a different way, e.g. 'Ben / pen' or 'Ben / Ben'. Three other practise pairs were also presented and feedback given to the child as required.

ABX

The ABX task was only presented at T2. The stimuli were the reduced set of 24 items (as selected by Stackhouse et al., 1999), as described earlier in this section (see Appendix 11). The procedure followed is as outlined in Chapter 3 (p. 109).

Speech Production

Naming

At T1, the stimuli were the reduced set of 24 items (as selected by Nathan, in prep.), as described earlier in this section (see Appendix 8). At T2, an additional 12 multisyllabic items were used, as described for the auditory discrimination picture task. The procedure followed is outlined in Chapter 3 (p. 109). For naming as a speech output processing task, scoring was based on whether of not the consonants were correctly produced. The measure is, therefore, of accuracy of speech production. This is in contrast to the naming of pictures in the Renfrew Word-finding Vocabulary Scale task, where scoring is for the use of the appropriate word, regardless of

accuracy of production. If the child misarticulates a word, but it is recognisable as the correct item, this will be scored as correct.

Word Repetition

At T1, the stimuli were the reduced set of 24 items (as selected by Nathan, in prep.), as described earlier in this section (see Appendix 8). For the second stage of the study (T2) the stimuli were extended. An additional 12 multisyllabic words were used, taken from Nathan (in prep.). These were low frequency words that were multisyllabic as longer words had been found to discriminate best between normal and clinical samples. They also contained clusters in order to reflect articulatory difficulty. The procedure followed is outlined in Chapter 3 (p. 110).

NWR

At T1, the stimuli were the reduced set of 24 items (as selected by Nathan, in prep.), as described earlier in this section (see Appendix 8). At T2, the list of stimuli was extended to include an additional 12 multisyllabic non-words (see Appendix 8). These were created to match the additional words used for word repetition, as described above (Nathan, in prep.). The procedure followed is outlined in Chapter 3 (p. 110).

Processing Rate Measures

Word repetition response time

At T1 and at T2 each child's responses to the word repetition task were tape-recorded. Timings were taken for 22 of the items that were included in both T1 and T2 stimulus sets. These were measured using waveform analyses of the recordings on a speech recognition programme, GoldWave Version 4.02 (Craig, 1998). Cursors were placed on the waveform to

measure the time taken from the start of each stimulus to the start of the child's response.

This is the same measure that Hitch et al. (1989b), Henry and Millar (1991) and Case et al. (1982) use as a measure of identification time. As already discussed in Chapter 2, it includes planning time for speech output, and therefore the use of the description 'identification time' may be misleading. Rather it might be seen as response time for word repetition.

NWR Response Time

At T1 and at T2, each child's responses to the non-word repetition task were tape-recorded. Timings were taken for 22 of the items that were included in both T1 and T2 stimulus sets. These were measured using waveform analyses of the recordings on the software programme GoldWave Version 4.02 (Craig, 1998) as described above for word repetition.

Picture Identification Response Time

At T2, each set of pictures used for the Spoken Input-Picture-pointing Output (SIPO) task (described in Chapter 5) were presented to the child. The child was asked to listen to the words and then to 'tap' the picture of the word as quickly as possible. The stimuli used in the SIPO task were spoken, live-voice, one at a time. The child's responses were tape-recorded. Timings were taken for 13 of the items. Time taken from the start of the stimulus to the sound of the child's 'tapping' of the picture was measured using the waveform analyses of the recordings on the software programme GoldWave Version 4.02 (Craig, 1998) as before.

The measure of 'identification time', used in previous studies (e.g. Case et al., 1982) is clearly not solely measuring speech input. Timing a picture-pointing response might eliminate the stages of speech output processing implicated in the repetition measure. However, this measure does involve the use of motor programming and planning for the hand movement of touching the picture. The time taken for this may have been artificially increased, because the children had to touch the pictures firmly enough to make a sound that could be used to measure a response time.

Speech Rate

As a practice item, each child was asked to repeat his name as quickly as possible until the tester said stop. If he / she was unable to maintain 10 repetitions, he / she was encouraged to keep going until the stop signal. At T1 several practice items were presented, the words baby, buttercup, and the syllables /fʌ/ and /lʌ/. For the syllables 20 repetitions were elicited. The test item was 20 repetitions of /pʌ/. Repetitions were counted at the time using a click counter, so that the stop signal could be given appropriately.

At T2, the practice items were the child's name and the tester's name. The test item was 10 repetitions of 'baby'. The test stimuli were designed to be as simple to produce as possible to reduce the motor execution demands of the task. Earlier pilot work, suggested that young children found it difficult to produce a multisyllabic word like 'buttercup' rapidly in sequence correctly and consistently.

Each child's response was tape-recorded and later analysed using waveform analyses of the recordings on the software programme

GoldWave Version 4.02 (Craig, 1998). Cursors were placed to count the 20 syllables required for the test items. The time taken from the start of the first syllable to the end of the twentieth syllable was then calculated.

Short Term Memory Tasks

Recalling Sentences

This sub-test from the Clinical Evaluation of Language Fundamentals (Semel et al, 1989) was presented. This task required the child to imitate a sentence spoken by the tester. The procedure and scoring described in the test manual was followed.

Fixed Length Word List

The experimental fixed list lengths for the Spoken Input - Spoken Output (SISO) task described in Chapter 5 (p. 184) were used at T1 and at T2. The procedure and scoring followed is described in Chapter 5.

6.5 RESULTS

Descriptive statistics were compiled for the measures used at T1 and at T2 (see Table 6.1). A composite speech production measure was calculated. This measure was the mean of the two z scores for the naming and word repetition tasks for each child, at T1 and at T2. A composite auditory discrimination measure was calculated. This measure was the mean of the two z scores for the auditory discrimination picture task and the same / different discrimination task for each child, at T1 and at T2. The ABX scores were not used in the auditory discrimination composite because this task had high STM demands. The analysis is concerned with trying to

untangle the roles of STM capacity and speech processing skill in language development.

Table 6.1: Mean (s.d.) of number of items correct for each speech processing, and STM task, and mean (s.d.) of time taken in seconds for speed of processing measures, at T1 and at T2

	T1		T2	
Task	**No of items**	**Mean (s.d.)**	**No of items**	**Mean (s.d.)**
STM - SISO	24	14.90 (4.30)	30	14.67 (4.63)
Aud discrimination picture task	48	43.19 (3.31)	72	60.72 (4.53)
Aud disc. same/different	20	14.91 (3.39)	18	14.57 (2.96)
Aud disc. ABX	-	-	24	17.88 (4.08)
NWR	24	17.33 (4.43)	36	19.52 (4.00)
Word repetition	24	18.29 (3.93)	36	25.90 (4.30)
Naming	24	16.95 (3.31)	36	29.57 (4.03)
Speech rate	-	5.78 (1.64)	-	5.46 (1.38)
Word repetition response time	-	12.66 (3.25)	-	12.88 (2.28)
NW repetition response time	-	15.46 (3.16)	-	14.04 (2.67)
Picture ID response time	-	-	-	20.37 (3.27)

The number of participants in this study is 21. This is a small sample size with which to investigate individual differences. However, in the interests of a thorough investigation into the relationships between the different variables, multiple regression analyses with up to 3 predictor variables were performed. The strength of the conclusions that can be drawn is limited.

6.5.i Relationships between NWR and STM and speech and language skills.

Do speech processing and STM capacity predict NWR?

Concurrent relationships

At T1 accuracy of NWR was significantly correlated with the speech production composite measure, but not significantly correlated with the auditory discrimination composite measure or with STM (see Table 6.2). As the speech production composite measure was significantly correlated with NWR, correlations between the individual speech production measures were examined. NWR was significantly correlated with both naming and word repetition, and to a similar degree ($r = .745$, $p < .001$, $r = .808$, $p < .001$).

At T2 accuracy of NWR was significantly correlated with the speech production composite measure, but not significantly correlated with auditory discrimination composite measure or with STM (see Table 6.3). Again NWR was significantly correlated with both naming and word repetition, and to a similar degree ($r = .471$, $p = .031$, $r = .454$, $p = .039$), but these correlations are not as strong as those found at T1.

Table 6.2: Correlational matrix for measures at T1

	Speech product	Auditory discrim	NWR	STM	Receptiv vocabul	Expressv vocabul	Receptiv grammar	Expressi grammar	Sentence repetitio	Speech rate	Word rep resp time	NWR resp time
Speech production	1.00	-0.154	-0.838**	0.047	0.134	-0.053	0.165	0.100	-.0.097	-0.185	0.110	-0.136
Auditory discrim		1.00	-0.029	-0..401	-0.546*	-0.554**	-0.656**	-0.079	-0.449*	0.480	0.462	0-.571*
NWR			1.00	0.188	0.037	0.217	0-.057	0-.018	0.315	-0.078	0.110	-0.067
STM				1.00	0.392	0.580**	0.215	0.114	0.824**	-0.215	-0.191	-0.222
Receptive vocabulary					1.00	0.747**	0.698**	0.367	0.471*	-0.299	0.030	-0.134
Expressive vocabulary						1.00	0.708**	0.491	0.619**	-0.105	-0.250	-0.300
Receptive grammar							1.00	0.266	0.396	-0.375	-0.157	-0.387
Expressive grammar								1.00	0.295	0.196	0.183	0.131
Sentence repetition									1.00	-0.195	-0.117	-0.112
Speech rate										1.00	-0.127	0.687**
Word rep resp. time											1.00	0.848**
NWR resp time												1.00

** significant at level of p<.01; * significant at level of p<.05.

Table 6.3: Correlational matrix for measures at T2

	Speech product	Auditory discrim	NWR	STM	Receptive vocab	Expr vocab	Receptiv grammar	Expr grammar	Sentence repetitio	Speech rate	Word rep resp time	NWR resp time	Pic ID resp time
Speech product	1.00	-0.020	0.504*	-0.129	0.220	0.180	-0.010	0.164	0.047	0.064	-0.269	-0.162	-0.100
Auditory discrim.		1.00	-0.070	0.490*	0.599**	0.544*	0.615**	0.303	0.470	-0.211	-0.073	-0.144	-0.569*
NWR			1.00	-0.077	-0.193	0.000	-0.140	0.067	-0.148	0.031	-0.301	0.049	-0.095
STM				1.00	0.159	0.088	0.292	0.229	0.400	-0.195	-0.136	0.038	-0.402
Receptive vocab					1.00	0.607**	0.639**	0.067	0.468*	-0..034	-0.231	-0.174	-0.383
Expressive vocab						1.00	0.570**	0.148	0.344	0.056	0.223	-0.023	-0.315
Receptive grammar							1.00	0.548*	0.727**	-0.138	-0.335	-0.267	-0.470
Expressive grammar								1.00	0.696**	-0.287	-0.479	-0.656**	-0.236
Sentence repetition										-0,368	-0.440	-0.427	-.0.388
Speech rate										1.00	0.016	-0.104	0.406
Word rep resp. time											1.00	0780**	0033
NWR resp time												1.00	0105
Pic ID resp time													1.00

** significant at level of p<.01; * significant at level of p<.05.

Predictive relationships

Correlations across T1 and T2 measures confirmed that NWR at T2 was significantly correlated with speech production at T1 ($r = .503$, $p=.02$), but not significantly correlated with auditory discrimination ($r = -.073$, $p = .754$) or STM at T1 ($r = -.108$, $p = .643$). NWR at T2 was significantly correlated with naming at T1 ($r = .528$, $p = .014$), but not with word repetition at T1 ($r = .404$, $p = .069$). These findings suggest that NWR is predicted by speech production skills but not by auditory discrimination or STM.

Is language development predicted by NWR or STM capacity?

Concurrent relationships

At T1 (see Table 6.2) NWR was not significantly correlated with any of the four language measures – receptive vocabulary (BPVS), expressive vocabulary (RWFS), receptive grammar (TROG) and expressive grammar (RAPT). STM was significantly correlated with expressive vocabulary, but not with any other of the language measures. At T2 (see Table 6.3) neither NWR nor STM were significantly correlated with any of the language measures.

Predictive relationships

However, correlational analyses across the two data collection points shows that STM skills at T1 are significantly correlated with both receptive and expressive grammar at T2, but not significantly correlated with vocabulary skills at T2 (see Table 6.4). NWR accuracy at T1 was not significantly correlated with any of the T2 language measures.

Table 6.4: Correlations between T2 language measures and T1 NWR and STM

	T2 Receptive vocabulary	**T2 Expressive vocabulary**	**T2 Receptive grammar**	**T2 Expressive grammar**
T1 NWR	.190	.117	-.037	-.060
T1 STM	.368	.347	.567**	.573**

** significant at level of p<.01; * significant at level of p<.05.

In order to confirm the independent predictive value of STM (at T1) for T2 grammatical skills, two multiple regression analyses were carried out with T2 receptive and expressive grammar as the dependent variables and T1 NWR and STM scores as the predictor variables. The two predictor variables were entered simultaneously to see which contributed the largest unique variance to performance on the language measures. For T2 receptive grammar, T1 STM was the strongest predictor (see Table 6.5), and the model was significant ($F_{(2,18)} = 4.702$, $p = .023$). For T2 expressive grammar, T1 STM was the strongest predictor (see Table 6.6), and the model was significant ($F_{(2,18)} = 5.02$, $p = .019$) .

Table 6.5: Simultaneous multiple regression analysis with T1 STM and NWR as predictor variables and T2 receptive grammar as the dependent variable.

Dependent variable: Receptive grammar at T2

	Unique r^2	**t value**	**Significance**
T1 NWR	.021	-.765	.454
T1 STM	.342	3.061	.007

Table 6.6: Simultaneous multiple regression analysis with T1 STM and NWR as predictor variables and T2 expressive grammar as the dependent variable.

Dependent variable: Expressive grammar at T2

	Unique r^2	t value	significance
T1 NWR	.029	-.906	.377
T1 STM	.35	3.153	.006

Grammatical development is predicted by STM capacity, but not by NWR. Other predictive relationships are not significant.

6.5.ii Relationships between speech processing and language skills and STM.

Do speech production and auditory discrimination skills predict STM?

Concurrent relationships

At T1 STM capacity was not significantly correlated with the speech production composite measure, however the correlation between STM and the auditory discrimination composite measure was stronger and approached significance (see Table 6.2). At T2 STM capacity was not significantly correlated with the speech production composite measure, but was significantly correlated with the auditory discrimination composite measure (see Table 6.3). As this relationship was based on a composite measure, Further correlational analysis showed that STM at T2 was significantly correlated with the auditory discrimination picture task ($r = .470$, $p = .032$) but not with same / different discrimination ($r = .380$, $p = .09$)

Predictive relationships

Correlations across time points showed that T1 speech production skills were not significantly correlated with T2 STM scores (r = -.361, p = .108). However, T1 auditory discrimination skills were significantly correlated with T2 STM scores (r = .594, p=.005). Further correlational analysis showed that STM at T2 was significantly correlated with both the auditory discrimination picture task at T1 (r = .481, p = .027) and with same / different discrimination (r = .495, p = .023). A simultaneous multiple regression analysis was carried out with STM at T2 is the dependent variable and the composite measures of speech production and auditory discrimination at T1 as the predictor variables (see Table 6.7). The model is significant (Total R^2=.427, F=.6712, p=.007)

Table 6.7: Simultaneous multiple regression, STM at T2 as the dependent variable, T1 speech production and auditory discrimination as predictor variables

Dependent variable: STM at T2

	Unique r^2	**t value**	**Significance**
T1 speech production	.075	1.53	.143
T1 auditory discrimination	.297	-3.05	.007

It is possible that the relationship between auditory discrimination and STM is a reciprocal one. As has already been reported above, the correlation between T1 auditory discrimination and T2 STM scores was significant (r = .594, p = .005). However, the correlation between T1 STM

and T2 auditory discrimination scores was not significant ($r = .366$, $p = .103$). Therefore, the direction of causality within this relationship is most likely to be of auditory discrimination skills influencing later STM capacity. The findings suggest auditory discrimination skills predict STM capacity, but speech production skills do not.

Does speech processing speed predict STM capacity?

Concurrent relationships

At T1 STM capacity was not significantly correlated with word or non-word repetition response time or with speech rate (see Table 6.2). However, word repetition response time was significantly correlated with non-word repetition response time. Speech rate was significantly correlated with non-word repetition response time, but not with word repetition response time (see Table 6.2).

At T2 STM capacity was not significantly correlated with word or non-word repetition response time or with speech rate. Neither was it significantly correlated with picture identification response time (see Table 6.3). However, word repetition response time was again significantly correlated with non-word repetition response time. Speech rate was not significantly correlated with non-word repetition response time, or with word repetition response time (see Table 6.3). Picture identification response time was not significantly correlated with any of the other timed measures.

Predictive relationships

When relationships across time are considered, T1 non-word repetition response time and speech rate were significantly correlated with STM at

T2 (r = -.705, p = .002, r = -.567, p = .018) but T1 word repetition response time was not significantly correlated (r = -.230, p = .392). This suggests that speed of processing may predict STM capacity, but this is only confirmed for some processing speed measures.

Do language skills predict STM capacity?

Concurrent relationships

As already presented in section 6.5.1, at T1 STM scores were significantly correlated with expressive vocabulary but not with receptive vocabulary or grammar or with expressive grammar (see Table 6.2). At T2, STM scores were not significantly correlated with any of the language measures (see Table 6.3).

Predictive relationships

Examining correlations across T1 and T2, there were no significant correlations between any of the T1 language measures and T2 STM scores (see Table 6.8). Language skills do not, therefore, appear to predict STM capacity.

Table 6.8: Correlations between STM at T2 and language measures at T1.

	T1 receptive vocabulary	**T1 expressive vocabulary**	**T1receptive grammar**	**T1 expressive grammar**
T2 STM	.204	.239	.320	-.220

** significant at level of p<.01; * significant at level of p<.05.

What best predicts STM?

Predictive relationships

As already reported language measures at T1 did not correlate significantly with STM at T2. However, non-word repetition response time and speech rate at T1 did correlate significantly with STM at T2, and auditory discrimination at T1 correlated significantly with STM at T2. These 3 variables were entered simultaneously into a multiple regression analysis with STM at T2 as the dependent variable. None of the predictor variables contributes a unique significant proportion of the variance to STM capacity (see Table 6.9). However, the model was significant (Total R^2 = .595, F = 4.909, p = .024) suggesting that these factors in combination do contribute to STM development, and their interaction is complex.

Table 6.9: Simultaneous multiple regression with STM at T2 as the dependent variable, and 3 predictor variables.

Dependent variable: STM at T2

	Unique r^2	**t value**	**Significance**
T1 speech rate	.058	-1.209	.258
T1 NWR response time	.052	-1.128	.286
T1 auditory discrimination	.019	.685	.509

6.5.iii Relationships between speech processing, STM and language development.

Do speech production and auditory discrimination skills predict language development?

Concurrent relationships

At T1, the auditory discrimination composite measure was significantly correlated with receptive vocabulary, expressive vocabulary and receptive grammar. It was not significantly correlated with expressive grammar (see Table 6.2). The speech production composite score was not significantly correlated with any of the language measures (see Table 6.2). At T2 the auditory discrimination composite was significantly correlated with receptive vocabulary, expressive vocabulary and receptive grammar. It was not significantly correlated with expressive grammar (see Table 6.3). The speech production composite score was not significantly correlated with any of the language measures (see Table 6.3).

Predictive relationships

Table 6.10: Correlations between standardised language measures at T2 and speech production and auditory discrimination at T1

	T2 receptive vocabulary	**T2 expressive vocabulary**	**T2 receptive grammar**	**T2 expressive grammar**
T1 speech production	-0.086	0.098	0.174	0.074
T1 auditory discrim	-0.735**	-0.409	-0.614**	-0.267

** significant at level of p<.01; * significant at level of p<.05.

Comparing performance across T1 and T2, T1 speech production skills did not correlate significantly with any of the T2 language measures, T1 auditory discrimination scores correlated significantly with T2 receptive vocabulary and receptive grammar. It was not significantly correlated with expressive vocabulary or expressive grammar (see Table 6.10).

A series of simultaneous multiple regression analyses were carried out with T2 receptive language measures as the dependent variables and T1 speech production and auditory discrimination measures as the predictor variables.

For receptive vocabulary at T2, auditory discrimination at T1 contributed .57 as a unique, significant proportion of the variance. Speech production at T1 did not contribute significantly (see Table 6.11). The model was significant (Total $R^2 = .584$, $F = 12.344$, $p < .001$).

For receptive grammar at T2, auditory discrimination at T1 contributed .36 as a unique, significant proportion of the variance (see Table 6.12). Speech production at T1 did not contribute significantly. The model was significant (Total $R^2 = .384$, $F = 5.599$, $p = .013$).

Table 6.11: Simultaneous multiple regression with Receptive vocabulary at T2 as dependent variable

Dependent variable: Receptive vocabulary at T2.

	Unique r^2	**t value**	**significance**
T1 speech production	.041	-1.322	.203
T1 auditory discrimination	.573	-4.956	<.001

Table 6.12: Simultaneous multiple regression with Receptive grammar at T2 as dependent variable

Dependent variable: Receptive grammar at T2.

	Unique r^2	t value	significance
T1 speech production	.0063	-.430	.673
T1 auditory discrimination	.356	3.224	.005

These findings suggest that auditory discrimination is a very substantial predictor of later receptive language skills but not expressive language skills. Speech production does not predict later language skills.

Does STM capacity predict language skills?

As presented in Section 6.5.i, STM scores at T1 were significantly correlated with receptive and expressive grammar at T2, but not significantly correlated with either receptive or expressive vocabulary scores at T2. So STM may predict grammatical development, but not vocabulary development.

What best predicts language development?

Predictive relationships

Relationships between language development and STM and speech processing skills have been explored, with significant correlations between STM and auditory discrimination and some language skills. As has already been reported in Section 6.5.i, NWR was not significantly correlated with language skills. A series of multiple regression analyses were carried out with T2 language measures as the dependent variables and T1 STM and

auditory discrimination as the predictor variables, entered together in the equation (see Table 6.13).

For *receptive vocabulary*, auditory discrimination contributed a significant proportion to variance (Unique R^2 = .411), STM did not contribute significantly, but the model was significant (R^2 = .546, F = 10.819, p = .001) (see Table 6.13). For *expressive vocabulary*, auditory discrimination contributed 0.086 of the variance, STM contributed 0.04 of the variance, but neither measure accounted for significant variation, and the overall model was not significant (R^2 = .207, F=2.352, p=0.124) (see Table 6.13).

Table 6.13: Simultaneous multiple regression analyses with language measures at T2 as the dependent variable, and auditory discrimination and STM at T1 as predictor variables. (Probability levels are given in brackets).

	T2 Receptive vocabulary		**T2 Expressive vocabulary**		**T2 Receptive grammar**		**T2 Expressive grammar**	
	R^2	**t value**	**R^2**	**t value**	**R^2**	**t value**	**R^2**	**t value**
T1 aud.	.41	-4.034	.08	-1.401	.17	-2.531	.00	-.221
Discrim.	1	(.001)	6	(.178)	8	(.020)	2	(.836)
T1 STM	.00	.503	.04	.954	.12	2.100	.25	2.639
	6	(.622)	0	(.353)	3	(.050)	6	(.017)
		F value		**F value**		**F value**		**F value**
Whole	.54	10.819	.20	2.352	.50	8.992	.33	4.441
model	6	(.001)	7	(.124)	0	(.002)	0	(.027)

For *receptive grammar*, both predictor variables were significant, auditory discrimination was the strongest predictor, contributing .178 to the variation, with STM contributing .123 of variance. The model was significant ($R^2 = .500$, F=8.99, p=0.002) (see Table 6.13). For *expressive grammar*, STM was strongest predictor, with a significant proportion of variation (Unique $R^2 = .257$). Auditory discrimination did not contribute any significant variation. The model was significant ($R^2 = .33$, F=4.441, p=0.027) (see Table 6.13).

Do STM and grammatical skills predict sentence repetition performance?

Concurrent relationships

At T1 sentence repetition was significantly correlated with STM, and with auditory discrimination, but not with either expressive or receptive grammar (see Table 6.2). At T2 Sentence repetition was again significantly correlated with auditory discrimination, and also with receptive and expressive grammar but not with STM (see Table 6.3).

Predictive relationships

Table 6.14: Correlational matrix for T2 sentence repetition and T1 auditory discrimination, grammar and STM measures.

	T1 auditory discrimination	**T1 receptive grammar**	**T1 expressive grammar**	**T1 STM**
T2 sentence repetition	.581**	.395	.281	.861**

*** significant at level of p<.01; * significant at level of p<.05.*

When comparing across the time points, T2 sentence repetition was significantly correlated with auditory discrimination and STM at T1 but not with either grammar measure at T1 (see Table 6.14).

Given that auditory discrimination has already been found to be significantly related to both STM and receptive and expressive grammar, further hierarchical multiple regression analyses were carried out, with auditory discrimination entered as the first step in the equation. STM, receptive and expressive grammar scores were then entered together as the second step in the equation (see Table 6.15). When variation in auditory discrimination scores was controlled for, by entering this as the first step in the multiple regression analyses, STM scores at T1 contributed significant additional unique variation (R^2 change =.444) in sentence repetition at T2, but receptive and expressive grammar scores did not (see Table 6.15). This suggests that STM predicts sentence repetition scores, independently of auditory discrimination skill, but grammatical knowledge does not.

Table 6.15: Hierarchical regression analyses, sentence repetition at T2 as the dependent variable.

Dependent variable: sentence repetition at T2

		R^2 change	Significance (p)
Step 1:	**T1 Auditory discrimination**	.336	.006
Step 2:	**T1 STM**	.444	<.001
	T1Receptive grammar	.0002	.872
	T1 Expressive grammar	.026	.127

6.6 DISCUSSION

The discussion presented here considers the issues that arise from the analysis of the data available but conclusions drawn are tentative, due to the small sample size. However, it is hoped that they will provide some insight into relationships between STM, language and speech processing in development.

6.6.i Do speech processing or STM skills predict NWR?

Concurrent relationships

The findings from this experiment are in agreement with those reported in Experiment 2, Chapter 4, in that speech production skills are strongly and significantly correlated with accuracy of NWR. However, auditory discrimination was not significantly correlated with NWR, whereas, this relationship had been found to be significant in Experiment 2. One reason for this different finding may be that there were a smaller number of participants from a restricted age band in this experiment, whereas Experiment 2 collected data from children across a 3 year age span.

In this experiment it was possible to compare the relative contributions of both speech processing and STM to NWR performance. NWR was clearly more strongly related to speech production than to STM, or to auditory discrimination. These findings confirm Gathercole and Adams (1993) results that NWR was more closely related to word repetition (which was one element of the composite speech production measure used here) than with digit span.

However, STM was not significantly correlated with NWR. This is in contrast to the findings of a number of studies by Gathercole and colleagues (e.g. Gathercole & Adams, 1993, Gathercole, 1995a, Adams & Gathercole, 1996, 2000, Gathercole et al, 1999). These studies reported that NWR was significantly correlated with performance on STM tasks such as word span and digit span. There are several differences in experimental procedure that may account for these differences in findings and these will be discussed later in this section.

The significant relationship between speech production skills and NWR was stronger between T1 measures than between T2 measures. This suggests that the relationship may change with age. At T1, when the children were aged 4;06 – 5;00 years, the prominence of speech production as the only significant correlate of NWR might be due to the variable maturity of speech output skills in young children. These children's phonological development might not be complete. For example, if a child is reducing clusters, saying /kəʊn/ for 'clown', then this process will operate on both naming and word repetition performance as well as on NWR. Another interpretation of this developmental difference in the relationship of speech production and NWR is that other factors may influence NWR as children get older. For example, greater use of top-down skills (i.e. existing lexical knowledge) may affect accuracy of NWR. However, as reported in Section 6.5.i, at T2 NWR was not significantly correlated with receptive or expressive vocabulary, which renders this interpretation unlikely.

Predictive relationships

Across time points, accuracy of the speech production task of naming at T1 was strongly and significantly correlated with T2 NWR performance. Auditory discrimination and STM scores at T1 were not significantly correlated with T2 NWR. These findings suggest that speech production skills may predict accuracy of NWR, and in particular the accuracy of motor programmes in the lexical representations, that are accessed for spontaneous rather than imitated production, may be important for imitation of unfamiliar items. This finding may support hypotheses that argue for an influence of lexical representation on NWR (e.g. Snowling et al., 1991, Dollaghan et al., 1993, 1995, Gathercole et al., 1991, Gathercole, 1995b). It may be easier to repeat non-words accurately if existing motor programs can be utilised in some way to support performance. In this study STM capacity was not found to predict NWR performance.

Methodological differences with studies by Gathercole and colleagues.

Conflicting findings from this study and those of Gathercole and colleagues may arise from methodological differences. In the experiment reported in this chapter, scoring procedures did not take account of the order of the words recalled in the STM task, just number of items correct. The studies of Gathercole and colleagues used measures of word and digit span that accounted for correct serial order of items. In NWR, for a response to be scored as correct, the phonemes must be recalled in the correct sequence. The correlations between NWR and STM, when serial order is being scored may reflect some common aspect of ordering of phonological information, rather than short-term storage of the material. Additionally, this experiment used a fixed list-length STM procedure,

other studies have used an increasing span task. This may also account for some differences in findings.

In this study, production of non-words was scored as correct if all the consonants were realised as the appropriate phoneme, although allowance was made for some commonly omitted phonemes, (see Chapter 3, p. 111). In some of Gathercole's studies credit is given in NWR scoring for consistent substitutions, although, each child's phonological system is not comprehensively analysed. This method of scoring may be haphazard and unreliable, in that the tester may observe one child making a consistent substitution, because this child has talked more, whereas a similar substitution may not be noticed in another, quieter child. Some developmental phonological processes do not operate consistently across all contexts. Sahlen et al. (1999b) have also commented on this scoring, arguing that some developmental phonological processes do not result in consistent substitutions, and so would then be scored as incorrect. In the experiment reported here, no allowance was made for developmental speech errors.

Another potential difference arises from the use of different non-word stimuli. In the experiment reported here, of the 24 non-word stimuli used at T1, 14 contained clusters, and there were 8 items at each word length 1 to 3-4 syllables. Of the 36 non-word stimuli used at T2, 23 contained clusters, and there were 8 items at each word length of 1 and 2 syllables and 20 at word length 3-4 syllables. In the stimuli lists used by Gathercole and Adams (1993) and Adams and Gathercole (1995), 6 out 15 stimuli contained clusters, and there were 5 items at each word length of 1 to 3 syllables. The stimuli used in the study reported in this chapter were,

therefore, phonologically more complex. One effect of this difference, and the more stringent scoring, as referred to above, was that NWR performance may have been more influenced by speech output, and motor execution constraints.

However, the Children's Test of NWR (CNRep, Gathercole et al., 1994) was used in some of the studies reported (Adams & Gathercole, 1996, Gathercole & Adams, 1994, Gathercole et al., 1999). Of the 40 stimuli, 23 contain clusters, although some items contain two or three clusters, and there are 10 stimuli at each word length of 2-5 syllables. The phonological complexity of stimuli in the CNRep is probably greater than in the study reported here, given that several of those stimuli contained 2 or 3 clusters. Scoring is based on the number of non-words with all phonemes correct, which is similar to the scoring used here, and so the use of different non-word stimuli cannot account for all of the difference in the finding of this study from previous studies by Gathercole and colleagues.

6.6.ii Is language development predicted by NWR or STM capacity

Concurrent relationships

NWR was not significantly correlated with any of the 4 language measures used. Again, these results run counter to the findings of earlier studies. However, different language measures have been used. For example, a significant relationship has been found between NWR and receptive vocabulary (Gathercole & Baddeley, 1989, Gathercole et al., 1992, Gathercole & Adams, 1993, 1994). In these studies the short form of the BPVS (Dunn et al., 1982) was used. This has already been criticised by van der Lely and Howard (1993) as being an insufficiently sensitive measure. The short form of the BPVS was designed as a screening

measure, not as a measure of language comprehension. In the experiment reported here the long form of the BPVS (Dunn et al., 1982) was used.

Significant correlations between NWR and expressive vocabulary have been found when the language measure was a word definitions task, (Gathercole & Adams, 1994), but not when it was a count of the numbers of different words used in spontaneous language (Adams & Gathercole, 1995). Neither of these tasks equate to the picture naming task used in this experiment.

NWR was significantly correlated with the usage of certain grammatical structures in spontaneous language (Adams & Gathercole 1995). However, this relationship was not consistent over all the types of grammatical structure counted, and, therefore, could not be considered as evidence of a robust relationship between NWR and expressive grammar. The findings of the experiment reported in this chapter support those of Bishop et al. (1996) who also found that NWR was not significantly correlated with receptive grammar (TROG, Bishop, 1989) for a mixed group of language impaired and normally developing children.

In this study STM was significantly correlated with expressive vocabulary at T1, but not with other language measures when the analysis was of concurrent data. Gathercole and Adams (1994) also found significant associations with expressive vocabulary, Adams and Gathercole (1995) did not, albeit for a different measure of expressive vocabulary. Adams and Gathercole (1995) also found digit span to be significantly correlated with some aspects of expressive grammatical usage. But in Gathercole and Adams' (1993) study, digit span did not correlate significantly with

receptive vocabulary. As discussed previously, different language measures have been used in these studies.

Predictive relationships

In this experiment, STM was found to be more strongly correlated with all language measures both within and across time points than NWR. This is contrary to the hypothesis that language development would be more strongly predicted by NWR than by STM. Based on concurrent data, Adams and Gathercole's (1995) study NWR was most strongly correlated with 2 measures of expressive syntax, however, digit span was more strongly correlated with all other measures of spontaneous use of expressive vocabulary and syntax. NWR was more strongly correlated than digit span with expressive and receptive vocabulary (Gathercole & Adams, 1994) and expressive language skills (Adams & Gathercole, 1996). Gathercole et al. (1999) found that expressive language was more strongly correlated with digit span than NWR in 4 year-olds. The arguments put forward in Section 6.6.i for differences in findings with regard to NWR and STM procedures are pertinent here.

Previous studies have not collected data on both NWR and STM and a range of language measures in the same group of children, at two time points, as was done here. Rather, these mixed findings have come from several studies using different language measures with different groups of children of different ages. In this study, significant correlations between STM at T1 and receptive and expressive grammar scores at T2 were found and multiple regression analyses confirmed that STM was a significant predictor of grammatical skills, but NWR was not. It is possible that the small sample size has reduced sensitivity to associations between NWR

and language performance, but that more substantial relationships, such as with STM, are registered.

6.6.iii Do speech production and auditory discrimination skills predict STM?

Concurrent relationships

Other studies in the field of STM development have not considered potential relationships with accuracy of speech production or auditory discrimination. In this study accuracy of speech production was not significantly correlated with STM. However, the finding of significant correlations between STM and auditory discrimination confirms findings from Gathercole et al. (1999) and supports hypotheses from Gathercole and Martin (1996) about the role of auditory skills in STM development. The finding that for T2 measures performance on the auditory discrimination picture task is more significantly correlated with STM than performance on same / different auditory discrimination is not expected. The same / different task has a slightly higher STM demand than the auditory picture task, and so might have been expected to correlate more highly with STM task. It does seem therefore that relationships between STM and auditory discrimination are not reliant on the STM demands of the tasks used. Rather it may be that long-term memory, in the form of existing lexical representations, might support both STM performance (as argued by Hulme et al., 1991, Roodenrys et al., 1993, Henry & Miller, 1993) and ability to judge the accuracy of words in the auditory discrimination picture task.

Predictive relationships

The correlational and multiple regression analyses of data across time points revealed that auditory discrimination scores at T1 significantly predicted STM at T2, but that speech production scores did not. Comparison of cross-time correlations confirmed that the relationship between auditory discrimination and STM was predictive in nature in that direction. This clear finding emphasises the role of accuracy, rather than speed, of speech input processing skills in the development of STM.

6.6.iv Does speech processing speed predict STM capacity?

Speech rate - Concurrent relationships

In this study speech rate, is not significantly correlated with STM when measured at the same time point. This is counter to previous findings of significant relationships between speech rate and STM (e.g. Hulme et al., 1984). However, Henry (1994) has argued that such relationships are mediated by age, and as the age range within this study is small, this may explain why these relationships are not found. Other studies (Gathercole & Adams, 1993, 1994, Gathercole et al., 1999) also failed to find significant relationships between speech rate and digit span. Most studies of STM that involve speech rate measures have relied on timing a child's repetitions of a word or words using a stop watch (e.g. Hulme et al., 1984, Henry, 1994). This study used a more accurate measure of measuring time taken from a display of the waveforms of the speech signals. This study used repetition of a syllable, /pʌ/, or a word, 'baby', stimuli selected to be relatively undemanding in terms of output processing skills. Some researchers have asked children to repeat multi-syllabic words and / or a sequence of two or three words (e.g. Hulme et al., 1984, Henry, 1994, Hulme & Tordoff, 1989). These measures may implicate motor planning and motor

programming aspects of speech processing in performance. Subsequent findings of a significant relationship between speech rate and STM may reflect a role for these more central levels of processing in STM task performance.

Identification time – Concurrent relationships

Measures of word and non-word repetition response rates, which are akin to the identification time measures in the literature, were not significantly correlated with STM. This confirms findings from Hitch et al. (1989b), but is discrepant from Henry and Millar (1991) and Case et al. (1982). One procedural difference is that Henry and Millar (1991) asked the children to repeat the words as quickly as possible. In this study, the children were not instructed to repeat the words quickly, rather the measure was of their natural rate for such a task. There were some technological difficulties in measuring the time between the stimuli and the start of the repetition. In the method used here, the waveform of the tape-recorded speech signals of stimulus and response were displayed. Cursors were used to measure the time between the start of the stimuli and the start of the child's repetition. Some difficulties with this process may have affected the accuracy of the data obtained. These included difficulty in: identifying the start of a vocalisation that began with a voiceless fricative, e.g. 'fish'; identifying the start of the child's repetition when this began before the presentation of the stimulus had finished; some children using a very quiet voice; background noise affecting the clarity of the waveform.

Speech rate was significantly correlated with NWR response time at T1 but not at T2, and was not significantly correlated with word repetition response time. This suggests that the relationship between speech rate and

other speech processing speeds may not be very robust. This may be because the speech rate measure used in this study required motor execution skills, but more central aspects of speech processing would be implicated in the repetition response times.

Speech processing speed - Predictive relationships

Although word repetition response time measured at T1 was not significantly correlated with STM at T2, both speech rate and non-word repetition response time measures at T1 were significantly correlated with STM at T2. This suggests that children who had faster processing skills for speeded repetition of a syllable, or for repeating non-words showed better STM task performance one year later. Given the lack of concurrent correlations, this finding was not expected, and these significant cross-time correlations were not confirmed by multiple regression when auditory discrimination at T1 was also entered into the equation.

This tentative relationship between speech rate, non-word repetition response time and STM development, may reflect speed and efficiency of speech processing skills in some way. Cowan and Kail (1996) have hypothesised that a global processing speed might be important in the development of STM. Mental processing speed may have some effect on speech rate and non-word repetition, although other factors are likely to be more influential.

6.6.v Do language skills predict STM capacity?

Concurrent relationships

Although sentence repetition and expressive vocabulary were significantly correlated with STM at T1, no other significant correlations were found

between STM and language measures at T1 or at T2. Other studies have found significant relationships between STM and performance on some language tests (Gathercole & Adams, 1994, Adams & Gathercole, 1995, Gathercole et al., 1999). As discussed in Section 6.6.ii, this has not been consistent across all language measures, and a different STM task was used in this study from that used in the studies by Gathercole and colleagues.

Predictive relationships

There were no significant correlations between T1 language scores and T2 STM. This indicates that language skills may not be influential in STM development, and is in contrast to the finding presented earlier that STM at T1 was significantly correlated with receptive and expressive grammar at T2. So, if there is a causal relationship between STM and language in development, it is more likely to be one in which STM plays a role in the development of at least some language skills, rather than vice versa.

6.6.vi Which measures best predict STM?

Predictive relationships

Three T1 measures had been found to be significantly associated with STM at T2, speech rate, NWR response time and auditory discrimination. Multiple regression analysis showed that although these skills at T1 did not individually contribute unique variance to STM, the three measures together did account for a significant amount of variance. So, these factors in combination contribute to STM development. Speech rate and NWR response time accounted for more of the variance than auditory discrimination. It may be that processing speed is more influential in STM performance than measures of accuracy of speech processing.

6.6.vii Do speech production and auditory discrimination skills predict language development?

Concurrent relationships

At T1 and at T2 auditory discrimination was significantly correlated with receptive and expressive vocabulary and receptive grammar, but not with expressive grammar. Speech production skills were not significantly correlated with any of the 4 language measures. This suggests that auditory discrimination skills may be important for language development.

Predictive relationships

Auditory discrimination scores at T1 were significantly correlated with receptive vocabulary and with receptive grammar measures at T2. This relationship with receptive language skills was confirmed by the results of the multiple regression analysis, with auditory discrimination accounting for a significant proportion of the variance in these language measure scores. Auditory skills have been considered important for normal language development (Ward, 1999) and in abnormal language development (e.g. Tallal, Miller, Bedi et al., 1996). The findings from this study would endorse such a view.

6.6.viii Does STM capacity predict language skills?

Concurrent relationships

As already discussed in Section 6.6.ii, a significant relationship was found between STM and expressive vocabulary at T1, but at T2 none of the language measures were significantly correlated with span.

Predictive relationships

Again, as already discussed in Section 6.6.ii, STM scores at T1 were significantly correlated with receptive and expressive grammar scores at T2. As auditory discrimination skills were significantly related to both STM and receptive language skills, STM and auditory discrimination were entered into a simultaneous regression analysis. STM was found to contribute unique significant variation in receptive and expressive grammar. This suggests that STM plays a unique role in predicting language development that is separate from the contribution of auditory discrimination skills.

6.6.ix Which measures best predict language development?

Predictive relationships

The multiple regression analyses show that auditory discrimination and STM skills both made a unique contribution to the variance for some language measures, however, the pattern was different for each language measure. For receptive vocabulary only auditory discrimination made a significant contribution to the variance. For expressive vocabulary, although auditory discrimination was the marginally stronger predictor, this did not reach significance. For receptive grammar, again auditory discrimination was the stronger predictor, with both auditory discrimination and STM accounting for a unique and significant

proportion of the variance. For expressive vocabulary, STM was the stronger predictor, this was significant, and auditory discrimination did not account for any significant variation. For expressive grammar, only STM made a significant contribution to the variance.

These findings suggest that the cognitive processes that underlie language development do not contribute to the same degree to different aspects of language. Auditory discrimination is the best predictor of receptive vocabulary and receptive grammar, STM is the best predictor of expressive grammar, and is also a significant predictor of receptive grammar.

6.6.x Do STM and grammatical skills predict sentence repetition performance?

Concurrent relationships

The sentence repetition task is sometimes used as a measure of expressive language development (e.g. Recalling Sentences subtest, CELF, Semel et al., 1987). However, this study shows that sentence repetition performance is significantly related to STM and auditory discrimination skills at T1, but not to grammar skills. At T2, auditory discrimination was still significantly correlated with sentence repetition, but so were receptive and expressive grammar. These findings confirm those of Blake et al. (1994) of a significant relationship between span and sentence repetition and of Bishop et al. (1996) of a relationship between receptive grammar and sentence repetition.

The change in significance of these relationships over time suggest that STM is more critical to sentence repetition performance in children under 5 years, but that for older children grammatical knowledge is more

important. This may reflect a change in the strategy used to perform this task. Younger children may be relying on bottom-up processing of the stimuli, whilst older children are beginning to use top-down processing and existing linguistic knowledge to repeat the sentences. These findings do suggest that for younger children sentence repetition may not be a reliable indicator of expressive language skills, but rather a reflection of STM capacity.

Predictive relationships

Auditory discrimination and STM scores at T1 were significantly correlated with T2 sentence repetition but grammatical skills were not. Given that findings from this study have already implicated auditory discrimination skills in both STM and grammatical competence, auditory discrimination could be influencing sentence repetition through both these other factors. However, STM was still a significant predictor of sentence repetition after controlling for auditory discrimination. Neither receptive nor expressive grammar score were significant predictors of sentence repetition.

6.7 GENERAL DISCUSSION

Conclusions can be drawn from this data about the relationships between STM, NWR, speech processing and language development in children aged 4 – 6 years. In the literature NWR has been used as a measure of PSTM. However, in this study accuracy of NWR was related to a child's speech production skills, and STM capacity was related to a child's auditory discrimination skills. This suggests that there is some dissociation between these two skills, and that caution should be taken in interpreting

claims for a relationship between STM and language skills, when NWR is the sole measure of STM. Further studies in this area may benefit from the use of a number of different measures of STM. Whilst NWR may be linked to language skills, this relationship may not be based in STM capacity, but rather in some other cognitive process or processes, associated with speech processing.

This study has found a significant relationship between accuracy of speech input processing (auditory discrimination) and STM capacity. Relationships are also found between some measures of speech processing speed and STM. The role of the efficiency and accuracy of speech processing skills in STM development warrants further study. Speech processing skills in children with speech and / or language difficulties may be compromised, and this may account for STM deficits in these children.

Auditory discrimination and STM also contribute to some aspects of language development. However, each of these factors predicted different aspects of language, and neither factor predicted performance on all 4 language measures. It should be noted that there was not a clear-cut split between expressive and receptive language skills and between grammatical and vocabulary knowledge. As auditory discrimination skills predict receptive language development and STM skills predict grammatical development, there are likely to be different mechanisms underlying these two sets of relationships. This suggests that studies in this field should include a range of language measures, and should confine interpretation of findings to the aspects of language that have been considered, rather than generalise findings to development of all language skills.

The numbers within this study are too small to allow fully developed path analyses to model the relationships between STM, speech processing and language in development. However, the statistical analyses carried out do allow an outline model to be hypothesised that shows significant relationships between these skills (see Figure 6.1).

Figure 6.1: Hypothetical model of the relationships between speech processing skills, STM capacity and language development. (Arrows indicate significant correlations between 4 year-old and 5 year-old measures, with the direction of the arrow from the 4 year-old measure to the 5 year-old measure.)

Within the framework of this hypothetical model, some speech processing speeds predict STM. It is clear that auditory discrimination skills play a causal role in the development of STM and in receptive language development, and that STM predicts the development of grammatical skills. The relationship between auditory discrimination skills and STM

has been investigated in only a few studies (e.g. Elliott et al., 1989, Watson & Miller, 1993). Elliott et al. (1989) also examined the relationship between auditory discrimination and receptive language and found significant correlations in task performances. This model also suggests that relationships between STM and grammatical development are unidirectional, so that STM predicts grammatical development, but language development does not predict STM capacity.

6.8 CONCLUSION

The research literature presents some conflicting findings, with the use of a range of methodologies and tasks, with groups of children of different ages. The experiment reported here has comprehensively considered relationships between speech processing skills and STM and language development in children who are developing normally. A carefully-selected wide range of tasks has enabled the effects of accuracy of speech processing, as well as processing rates, on STM and a range of different language functions to be evaluated. Longitudinal data has enabled the nature of relationships between different cognitive and speech processes to be explored, albeit within a relatively small sample.

Significant predictive relationships have been found. Speech production skills predict NWR; auditory discrimination and speech processing speed predict STM; auditory discrimination predict receptive language; and STM predicts grammatical development. A model of these significant relationships has been proposed. Auditory discrimination skills appear to play a key role in the development of both STM and receptive language.

CHAPTER 7
EXPERIMENT 5: INDIVIDUAL PROFILES OF SHORT-TERM MEMORY, SPEECH PROCESSING AND LANGUAGE IN CHILDREN WITH SPEECH AND LANGUAGE DIFFICULTIES

7.1 INTRODUCTION TO CHAPTER

Research findings suggest that short-term memory (STM) and non-word repetition (NWR) deficits are present in children with speech and language difficulties (Gathercole & Baddeley, 1990b, Montgomery, 1995a, Gillam et al., 1995, Bishop et al., 1996). There has been some debate about the nature of any relationship between STM deficits and language difficulties. The previous chapter, Chapter 6, explored the relationship between STM, NWR, speech processing and language development in children who are developing normally. A number of significant relationships were found, in particular between auditory discrimination and STM and some aspects of language development.

In this chapter, some of the research literature pertaining to STM and NWR deficits in speech disorder and in specific language impairment (SLI) will be presented. Experiment 5 will be reported, in which relationships between STM, speech processing and language development in individual children with speech and / or language difficulties will be examined. Findings will be considered in terms of the model (Figure 6.1, p. 257) proposed in the Chapter 6, to see if it offers useful insight into individual profiles in developmental disorder.

7.2 INTRODUCTION TO EXPERIMENT

7.2.i STM Deficits in Speech Disorder

A number of studies have investigated STM in children with speech difficulties. When a group of 5 to 6 year-old children with speech disorders were compared to a normal group, there was no difference in word or digit span recall. However, for a sentence repetition task the speech disordered children performed significantly less well (Saxman & Miller, 1973). These authors suggested that the children with speech disorders had a linguistic deficit, rather than a STM deficit, because sentence recall was more affected than digit or word span, and sentence repetition scores were significantly correlated with language comprehension and auditory discrimination performance, but not with articulatory errors.

In a study by Locke and Scott (1979), a group of 5 to 9 year-old children with speech disorders were significantly poorer at recall in a Picture Input – Picture Output (PIPO) task than a normal control group. There was also a stronger phonological similarity effect in the normal group. Locke and Scott (1979) suggested that this finding was the consequence of poorer sub-vocal rehearsal in the speech disordered children, that may arise as a result of their speech difficulty. However, more recent research, discussed in Chapter 2, Section 2.3.ii, suggests that many of the younger children in this study may not be expected to be using sub-vocal rehearsal.

In Chapter 2, several studies were presented that examined STM in children with speech difficulties, in relation to speech rate research. Raine et al. (1991) and C. Henry (1990), reported poorer STM performance and slower speech rates in their groups of speech impaired children. But, Bishop and Robson (1989) and White et al. (1994) found STM

performance in children with motor speech disorders was comparable to that of children with unimpaired speech.

There are, therefore, conflicting findings from the studies that have investigated STM in speech disordered children. These contradictions may arise from the use of different presentation and response mechanisms in the STM tasks. It is also possible that some types of speech disorder may be associated with STM deficits, whilst others are not. For instance, children with more peripheral, motor execution disorders may not experience associated STM difficulties (Bishop & Robson, 1989, White et al., 1994). Children with more central phonological processing disorders may be more likely to have STM difficulties.

7.2.ii STM Deficits in Children with Specific Language Impairment

It is also not clear whether language difficulties in children are always associated with STM deficits. Many studies of STM in children with language difficulties have compared their performance with that of control groups of children who are developing normally. The control groups are either age-matched, i.e. of the same chronological age as the children with specific language impairment (SLI), or language-matched, i.e. younger children who are performing at the same level as the SLI children on one or more standardised language measures.

Cowan (1996) hypothesises that STM deficits will affect language comprehension, making it difficult to retain information from preceding words and sentences to provide a context for understanding. Curtiss and Tallal (1991) explored the ability of children with SLI to understand short and long sentences with the same meaning. The long sentences contained linguistically redundant information, e.g. 'The girl who is smiling is

pushing the boy' vs. 'The girl smiling is pushing the boy'. The children with SLI were significantly poorer in their interpretation of the long sentences than an age-matched group, but showed a similar level of performance to language-matched children. Curtis and Tallal (1991) concluded that the children with SLI were more affected by the sentence length because of STM impairments.

A similar study was carried out by Montgomery (1995b) and poorer understanding of the longer sentences in the SLI children was confirmed. Montgomery (1995b) also found that the SLI children were significantly poorer at NWR than language-matched children for 3 and 4 syllable non-words, but not for 1 and 2 syllable non-words. This was interpreted to suggest that the SLI children had a PSTM deficit. Montgomery (1995b) argues that the NWR deficit reflects a capacity limitation in STM in SLI children, which affects their ability to process the longer sentences. NWR deficits in children with SLI will be discussed further in Section 7.2.iv.

However, factors other than memory may be involved in performance on such comprehension tasks. It is possible that the children with SLI perform less well on the longer sentences because these contained more complex grammatical structures, such as embedded phrases or clauses. Some grammatical deficit, rather than a STM deficit, may have resulted in greater difficulty in understanding these sentences. Van der Lely and Howard (1993) have argued that children's STM is constrained by their level of language development.

Some single case studies of children with SLI have been presented. Speidel (1993) reported longitudinal data comparing the bilingual language development of two siblings. One child had a history of early difficulties

with language development, in both languages (German / English), and continued to show poorer expressive language skills into the teenage years. He also had difficulty with STM tasks in early childhood, that was also evident at later testing. The STM deficit was most obvious for recall of unrelated words or digits, but performance on repetition of sentences was within the normal range. Baddeley and Wilson (1993) described an 8 year-old boy, who performed very poorly on digit span measures, word span and NWR. Further investigation showed that he had significant difficulties with vocabulary and syntax. However his speech rate did not differ from that of 8 year-old children without STM or language difficulties.

7.2.iii The Nature of the Relationship between SLI and STM Deficits

In the case studies by Speidel (1993) and Baddeley and Wilson (1993) the co-occurrence of poor STM and spoken language difficulties is reported. Baddeley and Wilson (1993) recognise that it would be premature to assume that language difficulties might follow directly from poor STM, in some causal relationship. However, they argue that, in this case, articulatory skills are normal and, although hearing difficulties were present at an earlier stage of development, hearing is now normal. So speech input and output processing was not thought to underlie the ongoing language and STM difficulties, rather that poor STM has played a crucial role in language development.

This is a somewhat simplistic view of the child's speech processing and language skills. Speech rate within the normal range does not imply that speech output processing is, or has been, normal. It can, also, be argued that early hearing difficulties might have an effect on language development (indeed Baddeley and Wilson (1993) acknowledge this argument, but then discount it) and normal hearing does not mean that all

levels of speech input processing are unimpaired. It is quite possible that this boy's STM and language difficulties are both correlate symptoms of some underlying speech processing, or other, deficit.

In Chapter 1, it was suggested that there are at least three alternative, possible relationships between SLI and STM deficits.

- STM deficits may be a causative factor in SLI
- STM deficits may be a consequence of SLI
- STM deficits and SLI may be correlates, co-occurring as symptoms of cognitive or processing difficulties.

A study by Gathercole & Baddeley (1990b), demonstrated that the word span of SLI children was poorer than that of age-matched and language-matched group, on a Spoken Input – Picture-pointing Output (SIPO) task. The SLI children were also poorer at repeating non-words, particularly those of 3-4 syllable in length. Gathercole & Baddeley (1990b) examined speech perception, with a same / different auditory discrimination task, and articulation skills, with a speech rate measure. For both measures there was a non-significant trend for the SLI to perform less well than the control groups. Gathercole & Baddeley (1990b) suggested that the SLI group had marked phonological memory difficulties, that were not the result of perceptual or articulatory deficits, but rather reflected "an impairment in the specialised storage of phonological information in working memory" (p. 357). Further, these authors hypothesise that "phonological storage skills play an important role in the development of a range of complex higher level linguistic abilities" (p. 357) and "that disordered language development may be a relatively direct consequence of phonological memory impairments" (p. 358).

This study collected data from a very small group of SLI children, only 5 or 6 such children participated at each stage of the study. The measures of speech perception and production were not particularly sensitive to subtle deficits in speech input and output processing. Neither was the measure used to match the SLI group with the language-matched group sensitive. The short form of the British Picture Vocabulary Scale (Dunn et al., 1982) is designed as a screening measure, with very few items, rather than as a measure with which to gauge the language age equivalence of a child. Whilst poor NWR and STM performance has been demonstrated in this group of SLI children, there is no evidence to confirm that these difficulties play a casual role in SLI. This view has been modified more recently. Gathercole and Martin (1996) suggest that the NWR deficit found in SLI children, which is what led Gathercole and Baddeley (1990b, 1993) to suggest the phonological loop was deficient, may arise from difficulties with speech perception.

Van der Lely and Howard (1993) found that SLI children performed as well as a group of language–matched children on a range of STM tasks, when the STM measure was for number of items correct. This suggests that SLI children have STM capacities that are constrained by the level of their language development. In this study the SLI children were more stringently matched with children of the same language level using three standardised language measures of both receptive and expressive skills. However, as with Gathercole and Baddeley's (1990b) study, data was collected from just 6 children with SLI.

Nation et al. (1999) argue that memory difficulties are concomitant with language impairments, and that strengths and weaknesses in basic language processes have an impact on verbal memory skills. Their study of children

with reading comprehension difficulties found effects of semantic familiarity on span, with differential performance on concrete vs. abstract words, so children with poorly developed semantic systems may have shorter spans.

Gillam, Cowan and Marler (1998) evaluated hypotheses about whether speech output constraints, auditory processing, or phonological coding skills played a part in the STM deficits observed in children with SLI. Performance on STM tasks with combinations of spoken and visual input and output mechanisms was compared. The data was interpreted to suggest that neither speech production constraints nor auditory deficits were responsible for poor STM recall. However, the case was argued for difficulties with the process of phonological representations, as needed for the phonological coding of stimuli, affecting STM performance. This argument could be taken a stage further. The integrity of phonological representations is also likely to be crucial to language development. So a difficulty with establishing phonological representations may underlie STM deficits and SLI.

Several studies have suggested that poorer STM in children with speech and / or language difficulties may arise from a difficulty with phonological coding of items to be recalled (Locke & Scott, 1979, Kirchner & Klatzky, 1985, Raine et al., 1991, Johnston & Anderson, 1998). However, other researchers found no difference in the recall of phonologically similar stimuli for children with and without SLI, suggesting that both groups are using phonological coding for STM recall of spoken word lists (van der Lely & Howard, 1993, Montgomery, 1995a, James, van Steenbrugge & Chiveralls, 1994). Such differences in findings may result from

methodological differences in selection of children with SLI, or in the STM tasks used.

Serial order recall in SLI

It may be that both STM deficits and SLI occur when some cognitive difficulty affects children ability to retain phonological information in sequence. A number of studies have suggested that STM is only deficient in children with SLI when the measure used is number of items given in the correct serial order. Van der Lely and Howard (1993) found that SLI children's free recall was equal to that of a language-matched group. However, when serial order was scored the SLI's performance was poorer, although not significantly so. A difficulty with recalling items in the correct sequential order was confirmed by Gillam et al. (1995). Their study showed that SLI children performed significantly less well in recalling lists of digits than age and language-matched control groups, when scoring was for number of items correctly recalled in serial order. But when scoring was for number of items recalled, regardless of order, the SLI children performed as well as the children in the control groups.

Kushnir & Blake (1996) reported no difference between SLI and age-matched controls on STM, when a Picture Input – Picture Output (PIPO) probed recall task was used. However, there were significant differences between the groups when the task was conventional word span recall. These authors suggest that the STM deficit in SLI children is for sequential memory, as serial order is being scored in the word span task, but not in the probed recall task. Another possible interpretation of the findings is of a verbal deficit, as the probed recall task could be completed non-verbally, but the word span task could not.

Auditory Discrimination Deficits

The findings of Chapter 6 identified a key role for auditory discrimination in development of both STM and receptive language skills. Auditory discrimination deficits have been identified in children with SLI and some researchers have argued that auditory discrimination deficits may be the underlying cause of SLI (e.g. Tallal and colleagues, see Bishop (1997) for a review).

Elliott et al. (1989) and Watson and Miller (1993) have found significant relationships between auditory discrimination and STM in children and young adults with language and reading difficulties. In Elliott at al.'s (1989) study scores on auditory discrimination measures could be used to correctly identify 80% of 6 to 8 year-old children for presence or absence of SLI, and were significantly correlated with performance on receptive language tests. These authors argue for auditory discrimination difficulties to be considered a casual factor in SLI. The findings from Chapter 6 could be interpreted to suggest that auditory discrimination difficulties may also cause STM deficits. Thus auditory discrimination difficulties may be an underlying deficit of which poor STM and SLI are correlated symptoms.

7.2.iv NWR Deficits in Children with SLI

Some of the research that has investigated the relationship between STM and SLI has used NWR as the measure of PSTM. Caution has already been expressed about the use of the NWR task in terms of the significant levels of speech processing required that is in addition to temporary storage capacity (see Chapter 4 for a review). However, when this task is used with SLI children a further caveat is required. Several studies have suggested specific NWR deficits in SLI children (Kamhi & Catts, 1986, Kahmi, Catts, Mauer, Apel and Gentry, 1988, Taylor et al., 1989, Bishop et al., 1996,

Edwards & Lahey, 1998, Dollaghan & Campbell, 1998). Sahlen et al. (1999b) found that NWR was significantly more difficult than word repetition for children with SLI.

Bishop et al. (1996) investigated children with a history of SLI and reported poor NWR performance even when language difficulties were no longer observed on standardised testing, i.e. language difficulties were considered to be resolved. Dollaghan and Campbell (1998) found that performance on a NWR task reliably identified children diagnosed with language impairments from age-matched controls. There was no overlap in NWR performance between the two groups and NWR identified the SLI children more reliably than a standardised language test. Findings from these two studies suggest that the NWR deficit found in children with SLI is persistent and robust.

Significant relationships have been reported between NWR and language measures in children who are developing normally (Gathercole et al., 1992, Adams and Gathercole, 1995) and this has already been discussed in Chapter 1. Several studies have also found significant relationships between NWR and both receptive and expressive language skills in children with SLI. (Kahmi et al., 1988, Bishop et al., 1996, Edwards & Lahey, 1998, Sahlen et al., 1999a,b)

Some researchers have interpreted the relationship between NWR difficulties and SLI to reflect a STM deficit (Gathercole & Baddeley, 1990b, Montgomery, 1995a). Whether or not the NWR difficulties are evidence for STM difficulties, it could be argued that a difficulty in perceiving and repeating sequences of novel phonological material (as required for NWR), might affect the development of language skills.

However, Bishop et al. (1996) suggest that as NWR deficits are also found in children with reading difficulties, who do not have significant problems with oral language, NWR deficits do not necessarily cause SLI. It may be that NWR is an outcome or symptom in children with SLI and reading difficulties rather than a causal deficit. Evidence from Kahmi et al. (1988) confirmed that SLI children performed as well as a reading impaired group on several NWR measures, except the repetition of multisyllabic non-words.

The hypothesis that a NWR deficit in children with SLI may indicate a PSTM difficulty arises in several studies. Children with SLI have been found to repeat shorter non-words as accurately as children without language difficulties, but to demonstrate significantly poorer repetition of longer non-words (Taylor et al., 1989, Gathercole & Baddeley 1990, Montgomery 1995, Bishop et al. 1996). This has been interpreted to suggest that STM capacity is reduced in the children with SLI. However, longer non-words contain more phonological material to be decoded and produced, and it is still possible for this differential performance across non-words of different lengths to arise because of increased speech processing demands.

Researchers have considered whether speech processing difficulties may underlie NWR deficits in SLI children.

Speech Input Processing

There was no significant difference in same / different auditory discrimination of words and non-words for the children with and without SLI (Gathercole & Baddeley, 1990b), although the children with SLI were significantly poorer at NWR. Edwards and Lahey (1998) examined errors made in NWR for unstressed syllables and for stop consonants, considered

to be difficult sounds for children with SLI to discriminate. Children with SLI did not make significantly more such errors than children with normal language. Edwards and Lahey (1998) concluded that auditory discrimination difficulties were not responsible for NWR deficits in children with SLI.

James et al., (1994) found that children with a central auditory processing difficulty, who exhibited many of the characteristics of SLI, were poor on NWR as compared to language level and age matched control groups. However, the language impaired children had significantly greater difficulty with a same / different auditory discrimination than children in both control groups, and significantly greater difficulty with an auditory lexical decision task than the age-matched control group. James et al. (1994) suggest that "the inferior auditory processing abilities may underlie the inferior phonological memory capacities of the CAP disordered children" (p. 325).

In Montgomery's (1995a) study, children with SLI had more difficulty in auditory discrimination of 4 syllable same / different non-word pairs than children without SLI, but performed comparably on 1 –3 syllable stimuli. Montgomery proposed that this may reflect a difficulty with speech perception, that could affect NWR performance. However, he also acknowledged that this finding could arise from a lack of sufficient capacity in PSTM for these longer stimuli.

Following a brief review of relevant literature, Gathercole and Martin (1996) identified the possibility that children with SLI may have impaired speech perception analysis skills. They suggest that "it is this impairment that lies at the root of their NWR ability" (p. 90).

Speech Output Processing

Speech output limitations on NWR were considered by Gathercole and Baddeley (1990b). There was no significant difference in speech rate, or in the pattern of performance across non-words with and without consonant clusters for children with SLI and with normal language. Gathercole and Baddeley (1990b) concluded that the NWR deficits of the children with SLI could not be accounted for by slower rates of articulatory rehearsal, or by limitations on speech output. James et al. (1994) and Montgomery (1995a) confirmed that there was no significant difference in speech rate between children with and without SLI.

Mixed findings are reported by Edwards and Lahey (1998) who investigated error patterns in NWR for consonant clusters and fricative and liquid sounds. The children with SLI did make more errors with consonant clusters than children with normal language, but this difference did not quite reach significance. The children with SLI also made significantly more errors on liquids and significantly less errors on fricative sounds. Edwards and Lahey (1998) considered this insufficient evidence to either accept or reject the hypothesis that NWR deficits in SLI are accounted for by motor execution difficulties.

However, Bishop et al. (1996) found that although SLI and control participants all showed an effect of consonant clusters (interpreted to be articulatory complexity) on NWR, there was an interaction between group and complexity, such that the SLI children were more affected by the presence of clusters. This may indicate that some output processing such as motor programming, planning or execution might have been less efficient in the SLI children.

NWR was significantly correlated with stage of phonological development, but not with oro-motor skills in a group of children with SLI (Sahlen et al., 1999b). This suggests that speech output skills might affect NWR, but not at the peripheral level of motor execution.

Summary of Section 7.2.iv

The relationship between NWR and SLI is not yet fully understood and NWR deficits may reflect limited STM capacity and / or difficulty with aspects of input and output speech processing. Some researchers have acknowledged the variability found within SLI children, such that some of them perform within the range of accuracy of NWR found in children who are developing normally (Bishop et al., 1996, Edwards & Lahey, 1998, Sahlen et al., 1999b). It would be interesting to look more closely at individual profiles of NWR and other skills in children with SLI, where possible relationships are not masked by group differences. As there is not yet clear agreement that PSTM is the only cognitive system that is implicated in NWR performance, findings from studies that suggest a STM deficit in SLI, but that only use NWR as the STM measure should be treated with caution.

7.2.v Differential Performance on STM Tasks

In Chapter 5, it was reported that there were significant differences in performance on STM tasks with contrasting presentation and response mechanisms in a group of normal children. Studies of STM in SLI children have also found differences in performance on different task paradigms. Van der Lely and Howard (1993) found that SLI children performed as well a language-matched group on a Spoken Input - Picture Output (SIPO) task. For a Spoken Input – Spoken Output (SISO) task there was a trend for them to do less well, although this was not significant.

Gillam et al. (1998) used digit span tasks with different combinations of spoken and visual input and output. Within the SLI group spoken responses were significantly more accurate than pointing responses, when input was visual, but not when input was spoken. (i.e. PISO better than PIPO, but SISO not better than SIPO). Gillam et al. (1998) comment on the 'unusual difficulty' that the SLI children have with pointing responses. It might be expected that children with speech and language difficulties would find tasks with pointing responses easier than with spoken responses, as did the normally developing children reported in Experiment 3 (Chapter 5). The pattern of performance of SLI across different STM task presentations may not mirror that found in the normally developing children.

7.2.vi Sentence Repetition

In Chapter 6, STM skills were found to significantly predict sentence repetition scores, but grammatical skills did not, in normal development. However, at the age of 5-6 years, grammar was significantly correlated with sentence repetition but not with STM. SLI children's sentence repetition performance was significantly affected by the grammatical complexity of the sentence to be repeated (Bliss & Peterson, 1975). The sentences were matched for length, thus equating the STM demands for simpler and more complex sentences. This effect was similar to the effect of grammatical complexity on performance of children who were not language impaired.

The case presented by Speidal (1993) performed within normal limits on a sentence repetition task, although word span performance was very poor. This suggests that, in this individual, STM was not the key skill required for sentence repetition, but rather the knowledge of sentence structure and meaning supported sentence repetition ability. Bishop et al. (1996) found

that in children with resolved and persistent language difficulties receptive grammar skills were significantly correlated with sentence repetition. These 3 studies all indicate that grammatical knowledge, rather than STM, plays an important role in sentence repetition in children with language difficulties.

7.3 RATIONALE FOR THIS EXPERIMENT

Several studies have attempted to explore the nature of the STM deficit in SLI children. However, there do not appear to be any studies in which longitudinal data is collected from children with speech and language difficulties. In order to uncover directions of causality in the relationship between STM deficits and SLI, longitudinal data is needed. This study examines children with speech and / or language difficulties at 2 time points, one year apart.

Researchers have tended to examine the performance of groups of children with speech disorder or SLI. However, clinical evidence often identifies these groups as being heterogeneous in nature. Group studies may obscure individual differences in speech and language processing skills, and in STM performance. This study uses a single case methodology. It was designed to investigate STM capacity, accuracy of NWR and relationships between STM, speech processing and language skills in children with speech and / or language difficulties.

The participants have been selected to represent a range of speech and / or language disorder. Their performance is evaluated in terms of the developmental speech processing model (Stackhouse & Wells, 1997), presented in Chapter 2 (p. 49). Distinction is made between speech input and output processing skills. The participants display underlying deficits at

different levels of processing. The study will examine how these different speech processing profiles affect STM and language skills. The participants are matched to the group of children studied in Experiment 4 (Chapter 6) for receptive language skills, and the longitudinal normative data reported in Experiments 3 and 4 (Chapters 5 and 6) is used to quantify performance.

The model presented in Chapter 6 (p. 257) is evaluated, to see whether it can be applied to clinical populations. This model hypothesised relationships between auditory discrimination and processing speeds and STM and between auditory discrimination and STM and some aspects of language development, in children who are developing normally. As with Experiment 4 (Chapter 6) a longitudinal perspective is taken, so that changes in the profile of performance across tasks can be evaluated.

7.3.i Predictions

Some general predictions are made as a result of the findings of Experiment 4 (Chapter 6). The proposed model presented in Chapter 6 (see Figure 6.1, p. 257) suggests that :

- As auditory discrimination skills predict STM development, children with auditory discrimination difficulties may also have STM deficits.
- As some speech processing rate measures predict STM development, children with slower speech processing rates may have STM deficits.
- As auditory discrimination skills predict receptive language development, children with auditory discrimination difficulties may have receptive language difficulties.
- As STM skills predict grammatical development, children with STM deficits may have grammatical language difficulties.

The finding of a significant relationship between speech production and NWR, from Experiments 2 and 4 (Chapters 4 & 6), would predict:

- Children with NWR deficits will also show speech production difficulties.

In addition to these general predictions, specific hypotheses will be made for each individual, or group of individuals, on a case by case basis

7.4 METHOD

7.4.i Experimental Design

This experiment was designed as a series of individual case studies. The performance of the participants, who have speech and / or language difficulties, is compared to that of a group of normal children who are at a similar level of receptive language. This means that some of the participants are older that the control group, and some are the same chronological age.

7.4.ii Participants

13 children with speech and / or language difficulties were assessed to take part in this experiment. The following criteria were used to select participants.

- Speech and/or language difficulties as diagnosed by a speech and language therapist.
- Age equivalent on one test of receptive language between 4;0 and 5;06.
- English as a first language.
- Non-verbal skills within the normal range, as evidenced by a scale score of 7 or more on the Block Design sub-test of the Wechsler Pre-school and Primary Scale of Intelligence (Wechsler, 1990) or Wechsler

Intelligence Scale for Children (Wechsler, 1992) (as appropriate to child's age).

- Passed hearing screen at 40dB, as described in Chapter 6, p. 214 (except for CB, see below).

The selection criteria led to data being excluded from two children, one whose scale score on the block design sub-test of the WISC was below 7, and another whose age equivalent receptive language scores were above a 5;06 year level. In many studies of children with SLI, their performance has been compared with that of children who are younger, but at a similar language level, the language –age match. In this study the participants with speech and / or language difficulties are compared with the normal children, aged 4 ½ to 5 years, from whom data was collected in Experiments 3 and 4 (Chapters 4 & 6).

The 11 children who participated in the study ranged in age from 4;01 to 8;02 years. The individual participants were deliberately selected to illustrate a wide range of type and severity of speech and / or language difficulty (see Table 7.1). Hearing was screened by the procedure described on page 214. All participants passed the hearing screen, except for CB. CB had a previously diagnosed hearing loss, and was included in the study for the purpose of examining the profile of STM and language performance in a case of hearing loss (i.e. difficulty with peripheral auditory perception).

Table 7.1: Age and language scores for participants with speech and / or language difficulty.

Participant	Age (yrs)	Nonverbal (block design) scale score	BPVS age equivalent (years)	TROG age equiv. (years)	Clinical Diagnosis
RF	7;00	11	4;11	5;03	Autistic spectrum disorder
KM	7;00	11	4;10	5;09	Language disorder
SB	5;04	10	3;11	5;00	Language delay
RN	8;02	16	4;10	5;03	Speech & language disorder
SA	6;10	7	5;09	5;00	Speech & language disorder
RW	6;11	7	5;00	5;06	Speech & language disorder
EP	4;01	10	4;07	5;03	Speech disorder
ZC	4;08	8	5;03	4;03	Speech delay
MG	4;11	11	4;10	7;00	Speech delay
BH	5;3	9	<3;00	4;06	Severe speech disorder
CB	6;02	13	3;10	5;00	Hearing loss

7.4.iii Experimental Procedure

As in Experiment 4 (Chapter 6) the entire battery of tasks were presented using one of four different orders of presentation, over 3 or 4 sessions with each child. Each child was seen in his / her own school, in a room or area away from the classroom, except for one pre-school subject (EP) who was seen in his own home. As in Experiment 4, participants were assessed at two time points, one year apart.

7.4.iv Task Procedures and Materials

The standardised language measures, speech production, processing speed and auditory discrimination tasks used in Experiment 4 (Chapter 6) were presented to these participants. In addition, the range of STM tasks with different presentation and response mechanisms from Experiment 3 (Chapter 5) were presented.

Standardised Language Measures

The standardised language measures were as used in Experiment 4, in Chapter 6. The procedure has already been outlined on page 215.

These were:

- Receptive vocabulary – British Picture Vocabulary Scale (Dunn et al., 1982)
- Expressive vocabulary –Word Finding Vocabulary Scale (Renfrew, 1995)
- Receptive grammar – Test for Reception of Grammar (Bishop, 1989)
- Expressive grammar – Action Picture Test (Renfrew, 1989)

Speech Processing Measures

The measures of speech production and auditory discrimination, speech and response rates were as used in Experiment 4 (Chapter 6). The stimuli and procedures have already been described (p. 216 - 220).

The *auditory discrimination measures* were:

- Auditory discrimination picture task
- Same / different auditory discrimination
- Non-word ABX

The *speech production measures* were:

- Naming

- Word repetition
- Non-word repetition

The *processing rate measures* were

- Speech rate
- Word repetition response rate
- NWR response rate
- Picture identification response rate.

Short Term Memory Tasks

The 3 different STM task paradigms were as used in Experiment 3, Chapter 5. The stimuli and procedures have already been presented (see p 184 - 185). The tasks were:

- Spoken Input-Spoken Output (SISO)
- Spoken Input- Picture-pointing Output (SIPO)
- Picture Input-Spoken Output (PISO).

The *Recalling Sentences* sub-test from the CELF (Semel et al., 1987) was also presented. The procedure has been outlined on page 222.

Measures of Task Performance

Mean and standard deviation of raw scores for these tasks were calculated for the group of children with normal speech and language development who were investigated in Experiments 3 and 4 (Chapters 5 and 6). This group data is referred to as the *control group*. Z scores were then calculated for performance on each task presented at each time point, for each participant with a speech and / or language difficulty. This individual data will be referred to collectively as the *clinical group*. Z scores of more than 1.65 or less than –1.65 are considered to indicate performance that is

significantly different from that of the control group, at the level $p < 0.05$. Recent clinical assessment had led to different editions of the Renfrew Word-finding Vocabulary Scales (Renfrew, 1988) and the British Picture Vocabulary Scales (Dunn, Dunn, Whetton & Burley, 1997) being used to collect some data from 5 participants. These scores could not be compared with the control group means. Therefore, scores were compared to the published normative data for 4;06 to 5 and 5;06 to 6 year-olds, and estimated z scores derived. Thus, the speech processing, memory and expressive language skills of the children are calibrated against normative data based on receptive language levels. Where z scores are discrepant, abnormal relations with receptive language skills are indicated.

7.5 CASE PROFILES

7.5.i RF

Introduction

RF was aged 7 years at T1 and attended a specialist school for children with specific and severe speech and language disorders. He has a communication disorder that falls within the autistic spectrum, and is characterised by difficulties with social communication and pragmatic aspects of language. His speech is clearly intelligible.

Predictions

Children with autistic spectrum disorders are usually described as having unimpaired PSTM skills (Russell et al., 1996, Donlan & Masters, 2000). As speech is clear, it is unlikely that RF has any speech processing deficits. It is predicted that:

- RF will not show any developmental STM or NWR deficit, relative to receptive language levels.

Results

Table 7.2: z scores for individual tasks for RF

RF	T1	T2
Receptive vocabulary – BPVS	.68	.15
Expressive vocabulary – RWFS	.22	$0
Receptive grammar – TROG	.36	.28
Expressive grammar – RAPT	-.04	.04
Auditory discrimination picture task	.85	-.38
Auditory discrimination – same/different	.56	.15
Auditory discrimination – ABX	-	1.25
Speech production – naming	.92	1.6
Speech production – word repetition	.18	**1.65***
Non-word repetition	.07	-.13
Speech rate	.42	-.67
Word repetition response rate	.4	-
Non-word repetition response rate	-.3	.57
STM – SISO	**1.88***	.07
STM – SIPO	**1.82***	.89
STM – PISO	-1.07	.76
Sentence repetition – CELF	.16	.22

* z score significant at level p<.05;

$ z score is estimated to be greater than 0 (as described on page 282).

RF's expressive language skills are at a similar level to his receptive language skills. Speech production skills are relatively advanced at T2, for word stimuli, whilst auditory discrimination performance and speech processing speeds are broadly in line with receptive language. STM capacity at T1 appears to be relatively advanced as compared to normative data based on receptive language level. However, STM skills are variable

at T1, with relatively good performance on SISO and SIPO, but poorer performance on the PISO task. These relatively good STM skills are not maintained between T1 and T2, but performance is more even across the 3 STM tasks. Sentence repetition is within the limits of control group performance. The longitudinal profile is not completely stable, with improvement in speech production skills, but a relative deterioration in STM skills (see Table 7.2).

RF's language, speech processing and STM skills are likely to be below expectations based on his age, given that he is about 2 years older than the control group.

Discussion

When compared to a group of normally developing children of the same level of receptive language, RF does not show STM or NWR deficits. This supports the prediction, that was based on the pattern that might be expected in a child with an autistic spectrum disorder diagnosis. In fact, RF performed relatively well on the STM tasks at T1 in comparison to the control group, although performance was not better than that of the control group at T2, and was demonstrating good speech production skills at T2. Receptive language level seems to be more specifically linked with auditory discrimination, NWR, speech processing speed and sentence repetition.

Reflecting on the proposed model of relationships based in normal development (Figure 6.1), RF's relatively good STM skills at T1 are not associated with well-developed grammatical skills. Neither do they seem to be the result of better than average auditory discrimination or processing

speed performance. However, RF is showing auditory discrimination and receptive language skills that are in line with each other.

7.5ii KM and SB

Introduction

Two children presented with resolving language difficulties, but with clear speech. KM was aged 7 years at T1 and attended a language support unit within a mainstream primary school. She has a history of severe language difficulties that are now improving, although language skills are still lagging about 2 years below the levels expected for her age. Her speech is clear. SB was aged 5;04 at T1 and attended a mainstream primary school. Her language skills were delayed initially, but these were now improving. She has poor vocabulary but clear speech.

Predictions

STM deficits have been found to be present in children with SLI. van der Lely and Howard (1993) have argued that STM skills will be comparable with level of language development. Bishop et al. (1996) have found NWR deficits in children whose language difficulties have resolved. The following predictions are made for these 2 children.

- KM and SB will not show any STM deficit as compared to the language-match control group
- KM and SB will show persisting NWR deficits.

Results for KM

KM's expressive and receptive language scores are at the same level as those of the control group, at both T1 and T2. Auditory discrimination and speech production skills and speech processing speeds are in line with those of the language-match control group. There are no STM or NWR

deficits when compared to control group performance. Sentence repetition seems to be weaker than most other skills. The longitudinal profile is relatively stable (see Table 7.3).

Table 7.3: z scores for individual tasks for KM

KM	T1	T2
Receptive vocabulary – BPVS	.58	.82
Expressive vocabulary – RWFS	1.35	1.64
Receptive grammar – TROG	1.2	.98
Expressive grammar – RAPT	1.52	-1.01
Auditory discrimination picture task	.55	1.39
Auditory discrimination – same/different	1.5	1.16
Auditory discrimination – ABX	-	1.01
Speech production – naming	1.53	-.14
Speech production – word repetition	.94	1.65
Non-word repetition	.38	.87
Speech rate	.68	.09
Word repetition response rate	-.08	.24
Non-word repetition response rate	.08	.05
STM – SISO	.02	.72
STM – SIPO	.65	1.3
STM – PISO	1.12	.47
Sentence repetition – CELF	-.75	-.92

* z score significant at level $p<.05$;

KM is about 2 years older than the control group, and so language, speech processing and STM skills are likely to be below expectations for her chronological age.

Results for SB

Table 7.4: z scores for individual tasks for SB

SB	T1	T2
Receptive vocabulary – BPVS	-.58	-.02
Expressive vocabulary – RWFS	**-2.03***	.03
Receptive grammar – TROG	-.06	-1.12
Expressive grammar – RAPT	.35	-.74
Auditory discrimination picture task	.66	.28
Auditory discrimination – same/different	.32	-1.54
Auditory discrimination – ABX	-	.52
Speech production – naming	-.29	-.39
Speech production – word repetition	-.33	-.44
Non-word repetition	-.07	-.38
Speech rate	.57	-
Word repetition response rate	-.48	.79
Non-word repetition response rate	-	-.67
STM – SISO	-.91	.5
STM – SIPO	-1.3	.48
STM – PISO	-.25	-.98
Sentence repetition – CELF	-1.49	-1.11

* z score significant at level $p<.05$;

SB is showing relatively poor expressive vocabulary at T1 but this had dramatically improved, to be comparable with that of the control group by T2. Other language skills were not significantly different from those of the control group. Performance on all speech processing and STM tasks is inline with expectations based on receptive language level. The longitudinal profile is relatively stable, apart from the marked improvement in expressive vocabulary (see Table 7.4). As SB is only a few months older

than the control group, her profile is likely to indicate speech, language and STM skills within the normal range at T2.

Discussion

These two children have a history of significant language difficulty, that is resolving. Neither of them is showing any STM deficits when performance is compared with that of children with a similar level of receptive language. This supports the prediction, and agrees with van der Lely and Howard's (1993) findings of STM performance in children with SLI that is in line with that of language-matched controls. These two children are not showing a NWR deficit when compared with a language-match group. This is contrary to the prediction made and in contrast to Bishop et al. (1996) who reported NWR deficits in children with resolved language difficulties. However, the Bishop et al. (1996) study used an age-matched control group. KM may demonstrate STM and NWR deficits when compared to other 7 and 8 year-old children, as she is older than the control group. It is likely that SB's STM and NWR skills are within normal limits for her age, given that she is almost the same age as the control group. KM and SB are showing similar developmental patterns, and sentence repetition is the weakest area for both these children.

SB is showing a significant difficulty with expressive vocabulary, which resolves by T2. Consistent with the model presented in Chapter 6, Figure 6.1, there is no evidence that SB's expressive vocabulary development is related to change in speech processing or STM skills. Evidence from both of these children supports the proposed model. Auditory discrimination and speech processing speeds are in line with STM skills. There are no discrepancies between auditory discrimination skills and receptive language, and between STM and grammatical development.

7.5.iii RN, SA and RW

Introduction

Three children presented with severe, mixed speech and language disorders. All 3 children were attending a specialist school for children with specific and severe speech and language disorders. RN was aged 8;02 at T1. He has a language disorder, with both expressive and receptive difficulties, immature speech, some autistic type behaviour and markedly poor attention control. SA was aged 6;10 at T1. He has difficulties with both expressive and receptive language and speech is unclear. RW was aged 6;11 at T1. He has been diagnosed as having an XXYY chromosomal anomaly. Published case studies of individuals with this condition have described poorly developed phonological systems (Garvey & Kellett, 1975) and verbal skills poorer than performance skills (Lee, 1996). RW has a severe phonological disorder, his speech is often unintelligible. His expressive language skills are also poor.

Predictions

Case history information and clinicians reports suggest that these 3 children have severe and persistent speech and language difficulties. Receptive vocabulary will be at the same level as that of language-match control group, as this was one of the selection criteria. However, there may be expressive language deficits. As speech is unclear, it is likely that z scores on the speech production measures, including NWR will be poor. Auditory discrimination difficulties may also be evident. As for KM and SB, STM may be expected to be in line with the level of language development (van der Lely & Howard, 1993). The following predictions are made for these 3 clinical cases.

- RN, SA and RW will show expressive language difficulties, as compared to receptive language-matched controls.

- RN, SA and RW will have auditory discrimination difficulties relative to control group performance.
- Z scores for speech production tasks, including NWR, will be significantly poor.
- RN, SA and RW will not show STM deficits, as compared to language-matched data.

Results for RN

RN's expressive grammar was poor at T1 but had dramatically improved by T2. Other language skills were comparable with those of the language-match control group. RN shows significant difficulty with both input and output speech processing that is accumulating over time. However, speech processing speeds are within the expectations based on the language-match control group performance. RN is not displaying any STM deficit as compared to the control group. There is, however, a significant difficulty with sentence repetition. RN's longitudinal profile is changing over time, with improvement in some language skills, but a relative deterioration in speech processing skills (see Table 7.5).

RN is 3 years older than the control group, so this profile suggests that language and STM skills may be poor for his age. Auditory discrimination and speech production are likely to be very poor when compared to chronological age control data.

Table 7.5: z scores for individual tasks for RN

RN	T1	T2
Receptive vocabulary - BPVS	.47	$0
Expressive vocabulary – RWFS	.41	#-1
Receptive grammar – TROG	.36	.98
Expressive grammar – RAPT	**-1.79***	1.36
Auditory discrimination picture task	**-1.57***	**-1.92***
Auditory discrimination – same/different	-1.15	**-2.22***
Auditory discrimination – ABX	-	-.95
Speech production - naming	-1.19	**-2.37***
Speech production – word repetition	-1.35	**-2.53***
Non-word repetition	**-1.65***	-1.63
Speech rate	1.04	1.35
Word repetition response rate	-.69	.05
Non-word repetition response rate	.08	-1
STM – SISO	-.67	.07
STM – SIPO	-.13	1.3
STM – PISO	.58	1.05
Sentence repetition - CELF	**-2.48***	**-2.54***

* z score significant at level p<.05;

$ z score is estimated to be greater than 0, # z score is estimated to be greater than –1, (as described on page 282).

Results for SA

Table 7.6: z scores for individual tasks for SA

SA	T1	T2
Receptive vocabulary – BPVS	1.52	@1
Expressive vocabulary – RWFS	.79	$0
Receptive grammar – TROG	-.06	.63
Expressive grammar – RAPT	**-2.57***	**-2.06***
Auditory discrimination picture task	-.06	-.6
Auditory discrimination – same/different	-.56	-.53
Auditory discrimination – ABX	-	-.71
Speech production - naming	**-3.31***	**-3.86***
Speech production – word repetition	**-2.36***	**-4.4***
Non-word repetition	**-3.23***	**-4.13***
Speech rate	.95	1.45
Word repetition response rate	.66	**1.72***
Non-word repetition response rate	.06	**1.85***
STM – SISO	**-2.3***	-1.22
STM – SIPO	-.52	**-2.36***
STM – PISO	-.52	-.98
Sentence repetition - CELF	**-2.23***	**-2.16***

* z score significant at level p<.05;

@ z score is estimated to be greater than 1, $ z score is estimated to be greater than 0, (as described on page 282).

Expressive grammar was poor at T1 and at T2 for SA. However, receptive vocabulary is a relative strength and by T2 was age-appropriate. Other language skills are comparable with those of the language-match control group. Auditory discrimination skills are in line with expectations based on receptive language skills, but there are substantial, and accumulating,

speech output difficulties. Speech processing rate measures are within the expectations based on the language-match control group performance at T1 and repetition response rates are significantly higher than expected at T2. There is some variability in SA's STM performance. At T1 there is significantly weaker performance on the SISO task, this had improved somewhat by T2. At T2 performance on the SIPO task appears to have deteriorated and is significantly below the level of that of the control group. SA is showing a significant difficulty with sentence repetition. SA has a longitudinal profile that is showing improving language skills, but with speech production skills becoming more discrepant as he gets older. The longitudinal profile also shows variable STM skills across both time points (see Table 7.6).

As SA is about 2 years older than the control group children, apart from receptive vocabulary, language skills will be below the level of age-matched data, and expressive grammar, is likely to be very poor for his age. There are likely to be STM deficits evident if SA's scores were compared to expectations based on his chronological age, and speech production, including NWR, is likely to be very impaired for his age.

Results for RW

RW's expressive grammar scores were poor at T1 and at T2. Other language scores are in line with those of the language-matched control group. There is an accumulating difficulty with auditory discrimination skills, with significantly discrepant z scores at T2. There are substantial and significant speech production difficulties, although these are stable from T1 to T2. However, speech processing rate measures are within the expectations based on the language-match control group performance. RW's STM performance is very variable. At T1, performance is as

expected when compared to the language-matched group. At T2, performance on the SIPO task is markedly poor, but, on the PISO task, is significantly better than expected. RW has significant difficulty with sentence repetition. The longitudinal profile shows stability of language development and speech production difficulties. Auditory discrimination deficits are becoming more apparent and STM performance is quite variable (see Table 7.7).

Table 7.7: z scores for individual tasks for RW

RW	T1	T2
Receptive vocabulary - BPVS	.79	-.1
Expressive vocabulary – RWFS	$0	$0
Receptive grammar – TROG	.78	.28
Expressive grammar – RAPT	**-2.57***	**-2.32***
Auditory discrimination picture task	-.66	**-2.59***
Auditory discrimination – same/different	-.86	**-2.56***
Auditory discrimination – ABX	-	-1.44
Speech production - naming	**-4.82***	**-4.86***
Speech production – word repetition	**-4.15***	**-4.16***
Non-word repetition	**-3.69***	**-4.63***
Speech rate	-.84	-1.01
Word repetition response rate	-.08	-.31
Non-word repetition response rate	-1.14	-.67
STM – SISO	-.67	.07
STM – SIPO	-.13	**-4.8***
STM – PISO	-1.62	**2.51***
Sentence repetition - CELF	**-2.56***	**-3.2***

* z score significant at level p<.05;

$ z score is estimated to be greater than 0, (as described on page 282).

RW is 2 years older than the control group children. His performance suggests that his language skills are not age appropriate, and expressive grammar is most affected. He is demonstrating very poor speech production skills, reflecting the severe phonological disorder, accompanying his medical diagnosis, that has been described in the literature (Garvey & Kellet, 1975). Auditory discrimination difficulties are also emerging as he gets older. STM performance is very variable and is unlikely to be age appropriate.

Discussion for RN, SA & RW

As predicted, comparative difficulties with expressive grammar were found for these three children, although this has resolved at T2 for RN. The proposed model predicted a role for STM (based in SISO task scores) in expressive grammar development. As RN has relatively intact STM performance, his improvement in grammatical skills is consistent with the model. In the case of SA, the difficulties with the SISO task and expressive grammar co-occur at T1, but by T2 STM has become comparable to that of the language-matched group. At T2 expressive grammar is improving, although still poorer than that of the control group. If the model proposed is appropriate, then one would predict that as STM improves, grammatical skills would also improve. RW does not show comparative difficulties with the SISO task, but has consistently poor expressive grammar skills, and this is not consistent with the proposed model.

The model predicts an association between auditory discrimination and receptive language. SA's receptive vocabulary knowledge has improved to an age appropriate level. This is not accompanied by a relative strength in auditory discrimination skills, which are on par with those of the language-matched control group. RN and RW are showing some auditory

discrimination difficulty but this is not associated with a corresponding receptive language difficulty, when compared to control group data. However, receptive language is likely to be below age appropriate levels. Auditory discrimination difficulties were predicted for these 3 children, and these are evident in RN and RW.

As predicted, RN, SA and RW do have significant and severe speech production difficulties. These are accumulating for RN and SA, and stable for RW. Given the difficulties with expressive grammar that are also found in all 3 children, speech production skills may impact on expressive grammar development. Although this correlation was not found to be significant in the data from the group of children who were developing normally, such a relationship may be characteristic of developmental disorder. RN whose speech production skills are not as impaired as those of SA and RW, is the only one of the 3 children to show significant improvement in expressive grammar between T1 and T2.

All 3 children showed NWR deficits. As predicted, these were associated with equally poor performance on naming and word repetition, and were more marked in SA and RW, who also showed more discrepant performance on the other two speech production measures. This agrees with the findings of Experiments 2 and 4 (Chapters 4 and 6) in which NWR was significantly correlated with speech production skills. In two of the three cases (RN and RW) this NWR deficit occurs in the absence of any STM deficit for SISO. Again this confirms findings of experiment 4 (Chapter 6) that STM was not significantly correlated with NWR. In SA who has poorer STM at T1, but a comparable level of STM at T2, there are no changes in NWR accuracy to mirror this improvement in STM.

The model predicts a relationship between auditory discrimination and STM. RN shows an interesting discrepancy between accumulating auditory discrimination and speech production difficulties with relatively good STM skills. RW is also showing an accumulating auditory discrimination difficulty that is not associated with a difficulty with the SISO task. However, RW is showing a very variable performance on the range of STM tasks, particularly at T2. This may reflect some confounding variable, such as inattention, which was quite marked in this child. SA also shows very variable performance on the STM tasks at T1 and T2, and again this may be the result of inattention or some other confounding variable. It was predicted that these 3 children would perform as well as the language-matched control group on the STM tasks. This is not supported by SA and RW's performance across all 3 STM tasks at both time points. As RN, SA and RW are 2 to 3 years older than the control group, they are very likely to demonstrate STM deficits when compared to expectations for their chronological age.

Sentence repetition performance is consistently poor in all three of these children. This is associated with poor STM at T1 for SA, but not for RN and RW. It is associated with some auditory discrimination difficulty in RN, and RW at T2. It may be associated with the poor expressive grammar skills found in all three cases. The findings of Experiment 4 (Chapter 6) were of significant correlations between grammar and sentence repetition in children over the age of 5 years.

Although common predictions were made for these 3 children with severe and persistent speech and language disorders, their developmental patterns of speech, language and STM performance show some differences, particularly in changes over time. There is evidence of expressive grammar

and sentence repetition difficulties in all 3 children and they all have marked speech production difficulties.

7.5iv EP, ZC and MG

Introduction

These 3 children are of the same chronological age as the control group. Their receptive language skills are, therefore, age appropriate, but they all have poor speech. EP was aged 4;01 at T1. He was a pre-school child, attending nursery school part-time. At T2 he was attending a main-stream primary school. He has a marked speech disorder, and his speech is often unintelligible. ZC and MG were aged 4;08 and 4;11 at T1. They both attended a mainstream primary school, and were selected for the study of children with normal speech and language skills reported in Experiment 4. The tester, an experienced speech and language therapist, noted that their speech development was delayed, with a range of developmental processes operating, and referred them for speech and language therapy assessment. ZC and MG were, therefore, not included in the group of children who are developing normally who participated in Experiment 4.

Predictions

As language skills are within normal limits, these children might not be expected to have any STM deficits. However, Raine et al. (1991) found slower speech rates and shorter word spans in children with speech disorders. There are, therefore, two competing predictions for STM development in these children.

- STM skills will be within normal limits.
- STM skills and speech rate will be poorer than expected for their age.

The children's poor speech would suggest the presence of speech processing difficulties, for speech production, including NWR, and possibly for auditory discrimination. The following predictions are also made for these 3 participants.

- EP, ZC and MG will have poor speech production skills, including NWR.
- EP, ZC and MG will show auditory discrimination difficulties.

Results for EP

Table 7.8: z scores for individual tasks for EP

EP	T1	T2
Receptive vocabulary – BPVS	.26	.07
Expressive vocabulary – RWFS	-1.47	1.1
Receptive grammar – TROG	.36	-.42
Expressive grammar – RAPT	**-1.79***	**-1.79***
Auditory discrimination picture task	-.36	.28
Auditory discrimination – same/different	-.86	-1.21
Auditory discrimination – ABX	-	**-3.65***
Speech production – naming	**-5.14***	**-5.6***
Speech production – word repetition	**-4.65***	**-4.63***
Non-word repetition	**-3.91***	**-3.13***
Speech rate	-1.04	.65
Word repetition response rate	.41	.54
Non-word repetition response rate	.31	.75
STM – SISO	-1.6	.72
STM – SIPO	-.52	.48
STM – PISO	-1.62	-.4
Sentence repetition – CELF	-.75	-.73

* z score significant at level p<.05;

EP is showing deficits in expressive grammar skills, but performance on the other language measures is not impaired. Although EP scores poorly on the auditory discrimination – ABX task at T2, this may reflect his young age, rather than an auditory discrimination difficulty. EP is actually a few months younger than the language-match control group. In Chapter 3, page 112, it was suggested that children under 5 years may not be able to complete this task. His performance on the other auditory discrimination tasks matches that of the control group. There is a substantial and significant speech production deficit that is stable across T1 and T2, including for NWR. However, NWR is not as impaired as performance on tasks with word stimuli, suggesting lexical representations are not accurate. Speech processing rate measures are comparable to those of the control group.

On the STM measures, EP's scores fall in the low-average range at T1 for the 2 tasks with spoken output, but have improved to be well within the normal limits for the control group by T2. Sentence repetition is within normal limits. The longitudinal profile is fairly stable, with some improvement in STM over time (see Table 7.8).

EP is 5 months younger than the control group children, he is not, therefore, showing any STM deficit for his age. Language is age appropriate except for expressive grammar. Auditory discrimination and speech processing speeds are in line with expectations for his age, but speech production is very impaired.

Results for ZC

Table 7.9: z scores for individual tasks for ZC

ZC	T1	T2
Receptive vocabulary – BPVS	1	.49
Expressive vocabulary – RWFS	-.53	-.5
Receptive grammar – TROG	-1.31	-1.12
Expressive grammar – RAPT	.94	.04
Auditory discrimination picture task	-1.27	.06
Auditory discrimination – same/different	-.56	-1.54
Auditory discrimination – ABX	-	-.46
Speech production – naming	**-3.31***	**-3.12***
Speech production – word repetition	**-4.15***	**-3***
Non-word repetition	**-2.33***	**-3.63***
Speech rate	.37	-.91
Word repetition response rate	-1.3	-.29
Non-word repetition response rate	1.18	.49
STM – SISO	-.67	-1.22
STM – SIPO	**-2.86***	.08
STM – PISO	-.79	-.98
Sentence repetition – CELF	-.5	-.83

* z score significant at level p<.05;

ZC is demonstrating language performance levels and auditory discrimination skills that are within normal limits. However, speech production is very poor and for NWR this deficit is accumulating across T1 and T2. Speech processing speeds are comparable to those of the control group. ZC shows an unexpected profile of STM performance, with poor SIPO performance at T1. At T2 this difference is no longer evident. Sentence repetition is unimpaired. ZC has a longitudinal profile that is

relatively stable, with some accumulation of the NWR deficit, but improvement in SIPO task performance (see Table 7.9).

As ZC is within the age range of the control group, she is clearly showing speech production difficulties, including for NWR. STM performance is variable at T1, but within normal limits at T2. Language and auditory discrimination skills are age-appropriate.

Results for MG

Table 7.10: z scores for individual tasks for MG.

MG	T1	T2
Receptive vocabulary – BPVS	.47	.15
Expressive vocabulary – RWFS	1.16	**1.99***
Receptive grammar – TROG	**2.03***	**2.38***
Expressive grammar – RAPT	-.62	.31
Auditory discrimination picture task	.55	.5
Auditory discrimination – same/different	1.21	-.87
Auditory discrimination – ABX	-	.03
Speech production – naming	**-3.31***	**-4.36***
Speech production – word repetition	**-2.87***	**-4.63***
Non-word repetition	**-2.11***	**-3.38***
Speech rate	.13	.48
Word repetition response rate	-.18	.37
Non-word repetition response rate	-.17	.23
STM – SISO	-.21	.72
STM – SIPO	.26	.89
STM – PISO	.85	.18
Sentence repetition – CELF	.9	1.17

* z score significant at level p<.05;

MG has some language scores that are significantly above the mean, suggesting that language skills are relatively well-developed. There is no evidence for auditory discrimination difficulty. However, there are substantial and accumulating speech production difficulties. Speech processing speeds are comparable to those of the control group. STM task performance and sentence repetition is within normal limits. The longitudinal profile shows improvement in language skills, but relative deterioration in speech production skills (see Table 7.10). As MG is within the age range of the control group, he clearly has a very specific difficulty with speech output processing, that is not associated with any STM or language difficulty.

Discussion for EP, ZC & MG

ZC is showing poor performance on the SIPO task at T1. This is unexpected and difficult to explain, especially as the picture-pointing response in this task, does not required speech production, which is ZC's weakest skill area. Apart from this one finding, as this group of children are chronologically age matched with the control group, it is possible to state categorically that they do not have any STM deficit, despite having severe speech difficulties. This confirms the prediction that STM skills are within normal limits. It is interesting to note that speech rate is not significantly slow. Both these findings are at odds with those of Raine et al. (1991), who suggested poor STM and slow speech rates in children with speech disorders.

These children are not showing any unexplainable auditory discrimination difficulty. This is evidence against the prediction that they may have auditory discrimination difficulties, and supports the model, with auditory discrimination developing in line with STM and receptive language skills.

However, they do have substantial, and in the case of MG accumulating, speech production difficulties. In all 3 children, poor NWR is associated with a similar level of difficulty with other measures of speech production, but not with poor STM task performance. This confirms the findings of Experiment 4 (Chapter 6).

Expressive grammar is poor in EP, but not in the other two children. In this regard EP is similar to the children presented in Section 7.5.iii, however, he is not showing the difficulty with sentence repetition that they are. This deficit in expressive grammar skills is associated with STM performance at T1 that is probably in the low-average range. However, STM performance has shown relative improvement in the year between T1 and T2, but expressive grammar has not. In the proposed model, STM skills predict later expressive grammar development, and it may be that improvement in STM at T2 will result in subsequent improvement in expressive grammar skills.

As with the children presented in Section 7.5.iii, this expressive grammar difficulty is in the context of a marked speech disorder, but is not evident in ZC and MG who also have a speech difficulty. Although the z scores for speech production tasks are similar for these 3 children, clinical judgement was that ZC and MG had a much less severe speech difficulty. Although several phonological processes were operating to result in consonant substitutions, these were akin to processes found in normal speech development, e.g. fronting. EP showed disordered speech with a reduced phonetic inventory and a marked lack of phonological contrast. His speech was often unintelligible, especially at T1, whereas ZC and MG's speech was usually intelligible.

7.5.v BH

Introduction

One child did not have any intelligible speech output. BH was aged 5;03 at T1 and attended a school for children with severe, specific speech and language difficulties. He was able to make a limited number of vocalisations, but these were not intelligible. He has some difficulty with oro-motor movement, tongue movements are slow and limited in range. His speech disorder may be the result of a severe motor deficit affecting motor execution for speech. BH was unable to complete any of the tasks that required spoken output.

Predictions

In investigating BH's speech processing skills, it was not possible to examine speech production, but if the locus of the speech disorder is in motor execution he would not be expected to display auditory discrimination deficits. If BH has a speech disorder that arises from motor execution difficulties, this would not be expected to have any effect on STM capacity (as demonstrated in the studies by Bishop and Robson (1989) and White et al. (1994)). The following predictions were made for BH's profile of performance.

- Auditory processing skills will be intact.
- STM will be within normal limits.

Results

BH's receptive grammar skills are comparable with those of the control group. His receptive vocabulary is poor at T1, but had improved to a comparable level by T2. BH showed a marked deficit in performance on the auditory discrimination picture task, and on the same / different task at T1 (data was not available on this measure at T2). Performance on the

SIPO task is within the limits of the control group data, although poorer at T2 than at T1. The longitudinal profile shows improving receptive vocabulary knowledge, and stable auditory discrimination deficits (see Table 7.11).

Table 7.11: z scores for individual tasks for BH

BH	T1	T2
Receptive vocabulary – BPVS	**-2.04***	@-1.5
Expressive vocabulary – RWFS	-	-
Receptive grammar – TROG	-.9	-.42
Expressive grammar – RAPT	-	-
Auditory discrimination picture task	**-5.19***	**-5.23***
Auditory discrimination – same/different	**-2.03***	-
Auditory discrimination – ABX	-	-1.19
Speech production – naming	-	-
Speech production – word repetition	-	-
Non-word repetition	-	-
Speech rate	-	-
Word repetition response rate	-	-
Non-word repetition response rate	-	-
STM – SISO	-	-
STM – SIPO	-.52	-1.55
STM – PISO	-	-
Sentence repetition – CELF	-	-

* z score significant at level p<.05;

@ z score is estimated to be greater than –1.5 (as described on page 282).

As BH is only 3 months older than children in the control group, his performance can be more or less directly compared as a chronological age

match. BH is, therefore, likely to be showing age appropriate receptive language at T2, and age appropriate STM. There is a substantial deficit in auditory discrimination, based on expectations for his chronological age.

Discussion

BH is showing a clear auditory discrimination deficit, contrary to the prediction. This suggests that, although there is a clear basis for suggesting that a motor execution deficit was underlying his lack of intelligible speech, poor auditory discrimination skills may also be contributing to his speech disorder

STM, as measured on the SIPO task, is within the normal range. This is in the presence of little speech, and, presumably, slowed speech rate. This finding is in accord with those of Bishop and Robson (1989) and White et al. (1994), that children with motor execution speech difficulties perform on STM tasks with picture pointing output at a similar level with non-speech disordered peers.

The proposed model suggests that auditory discrimination difficulties might impact on STM and receptive language development. Whilst receptive vocabulary is poor at T1, vocabulary has improved by T2, whilst auditory discrimination remains poor, so the relationship is not clear-cut. Poor auditory discrimination does not appear to have greatly affected STM in this case, although STM is a little poorer at T2 than at T1, it is not significantly so.

7.5.vi CB

Introduction

One child included in the experiment had a significant hearing loss, and, therefore, clearly a history of auditory input processing difficulty. CB was aged 6;02 at T1 and attending a support unit for hearing impaired children within a mainstream primary school. She has a moderate to severe bilateral sensori-neural hearing loss, diagnosed at age 4 years, and wears binaural hearing aids. When wearing her aids, hearing thresholds have been reported to be at 35 dB, however, she failed the 40 dB hearing screen carried out for this experiment. Her language skills are poor for her age, and there are a number of consistent substitutions in her speech.

Predictions

CB clearly has some auditory processing deficits at the peripheral level of auditory perception. Children with hearing loss usually have reduced STM spans for their age, and STM is correlated with the ability to use phonological coding (Campbell & Wright, 1990, Hanson, 1991). The model proposed in Chapter 6 also predicts knock-on effects of poor auditory discrimination on STM capacity and on receptive vocabulary and grammar development. One would expect that poor speech input processing will affect the creation of accurate phonological representations and so there may be errors in speech production. The following predictions are made for CB's profile of performance.

- Performance on auditory discrimination tasks will be below that of the control group.
- As auditory discrimination predicts STM in normal development, CB will demonstrate STM deficits.

- As auditory discrimination skills predict receptive language development, receptive language development will be below normal limits.
- CB will make speech production errors.

Results

Table 7.12: z scores for individual tasks for CB

CB	T1	T2
Receptive vocabulary - BPVS	-.68	-.52
Expressive vocabulary – RWFS	-.53	.21
Receptive grammar – TROG	-.06	-.77
Expressive grammar – RAPT	-.62	**-2.06***
Auditory discrimination picture task	**-5.19***	**-2.59***
Auditory discrimination – same/different	**-1.74***	-1.21
Auditory discrimination – ABX	-	-.22
Speech production – naming	**-3.91***	**-4.36***
Speech production – word repetition	**-3.38***	**-4.4***
Non-word repetition	**-2.78***	**-3.13***
Speech rate	1.12	.06
Word repetition response rate	.43	.13
Non-word repetition response rate	.62	.9
STM – SISO	.02	-1.01
STM – SIPO	-.13	.08
STM – PISO	.3	-1.27
Sentence repetition – CELF	-.83	-1.21

* z score significant at level p<.05;

Language skills at T1 are within the range of those of the control group, but a difficulty with expressive grammar has emerged at T2. As would be

expected, given the history of marked hearing loss, auditory discrimination is poor. However, performance on two of the auditory discrimination tasks at T2 is less impaired than at T1, and is improving. Speech production, including NWR, is also markedly poor, and tending to accumulate with greater discrepancy at T2. However, speech processing rates are equitable with those of the control group. Performance on the 3 STM tasks and on sentence repetition is within the limits of the control group performance. The longitudinal profile shows improvement in auditory discrimination, but a relative deterioration in expressive grammar and in speech production (see Table 7.12).

CB is about a year older than the children in the control group. Her performance suggests that receptive language and STM skills may be below normal limits for her chronological age. There is also likely to be an expressive language difficulty, especially for expressive grammar, relative to age. There will be substantial auditory discrimination and speech production deficits, if performance is compared to age-matched data.

Discussion

As predicted CB is showing auditory discrimination difficulties. The proposed model predicted that auditory discrimination difficulties would affect STM and receptive language skills. STM skills are in line with expectations based on receptive language level. However, CB is about a year older than the control group and so may show a STM deficit when compared with other children of her age. Studies that have suggested STM deficits in hearing-impaired children have tended to use age-matched control groups. It is possible that STM develops in line with the spoken language skills in hearing impaired children, in the same way that this is hypothesised by van der Lely and Howard (1993) for children with SLI.

Receptive language development is in advance of expectations based on auditory discrimination. This does not support the proposed model, in which auditory discrimination skills should predict receptive language. Expressive grammar is poor at T2. The model proposes a role for auditory discrimination in receptive grammar development, but not for expressive grammatical development. STM predicted expressive grammar development, but in this case the relative deterioration in expressive grammar is not preceded by a significant STM deficit relative to language level.

As predicted, there are substantial and accumulating speech production deficits, that are likely to be the result of impaired speech input processing. NWR is poor, and in line with the other speech production measures, but in the presence of relatively good STM skills. This is further confirmation of the pattern seen in other children in this study and of the findings of Experiments 2 and 4.

7.6 GENERAL DISCUSSION

This experiment has investigated speech processing, STM and language skills in children with speech and / or language difficulties. The comprehensive test battery has distinguished between speech input and output skills and processing speed, STM, and expressive and receptive language skills. Data is longitudinal, allowing changes over time to be examined. The participants scores on all measures have been compared to receptive language-matched, longitudinal control data. However, potential relationships between STM and auditory discrimination and receptive language skills may not have emerged, because the matching was carried out using performance on the receptive language measures. Where no

deficits in STM, accuracy or rate of speech processing, or language skills are reported, this is in comparison to younger children. In fact, STM, language and other processing deficits may well be present if the performance of these children were to be compared to chronological age norms. The points made in this discussion must be interpreted in the light of this caveat.

One clinical observation made at the time of testing was that attention control in most of the children in this clinical group was quite poor, when compared with that of the younger children in the control group. It was at times quite difficult to keep their co-operation and attention to the task. The clinical judgement of the tester, an experienced speech and language therapist, was that some of the scores obtained did not reflect an accurate level of competence. Visual inspection of some z score profiles shows a wide range of variability in performance on similar tasks, that may well have reflected this poor attention control. This means that the interpretation of data from this clinical group must be cautious. The general predictions made for these cases will now be evaluated.

7.6.i STM Capacity

The proposed model predicted that auditory discrimination, speech rate and non-word repetition response rate may influence STM capacity. For some of the children investigated, auditory discrimination and STM skills were at a similar level of competence to those of the receptive language-matched group. However, the participants displayed a range of performance profiles, as compared to the language –match control group. RN, BH and CB show some auditory discrimination difficulty but no deficit in STM performance. SA and ZC show no difficulty in auditory discrimination but variable STM performance. RW shows some difficulty in auditory discrimination and

some reduced STM performance, on the SIPO task, at T2. There is, therefore, no consistent evidence to support a clear relationship between auditory discrimination and STM in this group.

Speech processing rates were within the range of the receptive language-matched group. Although a small number of children showed selectively poor performance on one or other STM task, this was not associated with slower speech processing speeds.

A number of these participants did not show the same pattern of performance across the 3 STM tasks as the control group. Several children performed relatively more poorly on the SIPO task at one time-point or another (SB, RN, SA, RW, ZC). The SIPO task was found to be the easiest STM task for the control group (in Experiment 3, Chapter 5). One would expect, given the major speech difficulties some of these children are experiencing, that they would perform much better on a task where output was visual and motor, rather than verbal. It is possible that this reflects variable attention levels in the children, such that performance was not indicative of underlying competence. It is also possible that because the control group obtained the highest scores for this task, any subtle STM discrepancy is more obvious in the comparison on this task, rather than the other two STM tasks. Gillam et al. (1998) also found that a group of children with SLI performed less well on a SIPO task than a SISO task. These authors concluded that STM deficits arose in children with SLI because they had difficulty with phonological representation and, hence, with phonological coding of stimuli for recall. Difficulties may arise when the phonologically coded stimuli have to be transformed to a visually based representation for a pointing response.

Marked STM deficits were not evident in these children STM skills are broadly in line with expectations based on receptive language skills. This is similar to the finding of van der Lely and Howard (1993), which was interpreted to suggest that STM is limited by the level of language development. However, it is also possible to argue that language level is limited by STM capacity. It is also important to consider the nature of the STM deficit in children with speech and language difficulties. Some studies have suggested that the difficulty with STM is one of recalling items in the correct serial order (Gillam et al., 1995, Kushnir & Blake, 1996). Children with SLI appear to have a particular deficit in serial order recall, that might be the result of some difficulty with the sequencing of phonological material. In this study, the STM tasks were scored for free recall, and, therefore, serial order deficits would not be identified in these data.

7.6.ii Language Development

The model suggests that the development of receptive vocabulary may be predicted by auditory discrimination skills, receptive grammar predicted by auditory discrimination and STM capacity, and expressive grammar predicted by STM. As has already been mentioned, there will not be much evidence of comparative receptive language deficits in the clinical group, because these are the measures on which they are being matched with the control group. RF, KM, RN, SA, RW and CB are all older than the control group, and so they are displaying receptive vocabulary and grammar deficits for their age. BH also presents with a receptive vocabulary deficit at T1. RN, RW, BH and CB display auditory discrimination difficulty, relative to the control group, and this might be contributing to their receptive language deficits. For RF, KM and SA auditory discrimination is within expectations based on receptive language level, however, this may reflect auditory discrimination skills that are poor for their age, and, hence

a relationship between poor auditory discrimination and receptive language difficulties may still be evident

The data highlights comparative difficulties with expressive grammar in SA, RW, and EP at T1 and T2, RN at T1 and CB at T2. This grammatical difficulty is only associated with impaired STM skills in SA at T1 (SISO) and T2 (SIPO) and in RW at T2 (SIPO). Some concern has already been expressed about the validity of scores on these measures due to inattention. However, these children all have quite poor speech production skills, and this included poor NWR. Studies that have implicated STM in expressive language development, when using the NWR task, (e.g. Adams & Gathercole, 1995), may be revealing an association between expressive language and speech output rather than with STM. Experiment 4 (Chapter 6) was not able to demonstrate significant relationships between speech production and NWR and expressive grammar. It may be that this relationship arises in speech and language disorder but not in normal development. ZC and MG also had poor speech production, but expressive grammar skills within normal limits. However, as discussed in Section 7.5.iv, their speech errors showed characteristics of delay rather than disorder. It is possible that speech disorder is associated with poor development of expressive grammar, but speech production skills are not associated with grammatical development in the normal population.

7.6.iii Non-word Repetition

A number of the cases showed poor NWR, but always in the context of poor speech production skills (RN, SA, RW, EP, ZC, MG and CB). Of these children only SA and RW also show some poor performance on STM. This accords with the findings of Experiment 4 (Chapter 6) from the control group of significant correlations between NWR and speech

production but not with STM capacity. Therefore, to suggest that NWR deficits in children with SLI (e.g. Gathercole & Baddeley 1990b, Montgomery 1995a) are indicative of poor STM may be misleading. NWR deficits may arise in children with speech disorder or SLI as result of other speech processing deficits, particularly in speech output processing.

7.6.iv Speech Processing Speeds

Measures were taken of speech rate and word and non-word repetition response times (which equate to identification times used in the literature). It is interesting to note that none of these children with speech and / or language difficulties show deficits in speech processing speed, as compared to the receptive language-matched control group. Even the participants with marked speech disorders (RN, SA, RW, EP, ZC, MG and CB) do not have slower speech rates. This is counter to findings from C Henry (1990) and Raine et al. (1991) which suggested that children with speech disorders had slow speech and poor STM.

The model proposes that speech rate and NWR response time will predict STM development. For most of these children, speech processing speeds were in line with STM skills, when both were equated with receptive language-matched control group data. For the children who performed significantly below the control group scores on one or more STM task, there was no evidence of accompanying slower speech processing speeds. In fact, SA, who has a poor performance on SIPO at T2 has response rates that are significantly above those of the control group. These individual clinical cases, do not, therefore, demonstrate any clear relationship between speech processing speed and STM.

7.6.v Sentence Repetition

Three children with mixed speech and language difficulties (RN, SA and RW) showed poor sentence repetition, as compared to the control group. They also had difficulties with expressive grammar. Findings from Experiment 4 (Chapter 6) had suggested that grammatical skills predicted sentence repetition performance. However, EP and CB also had expressive grammar difficulties, but performed as well as the control group on sentence repetition. SA and RW had also demonstrated variable performance on some STM tasks, and it may be that a combination of poor grammatical development and variable STM can affect sentence repetition in clinical cases.

7.6.vi Summary

These children with speech and / or language difficulty are showing individual profiles of performance across this range of task and over time. Some relationships do seem to be emerging. Receptive language difficulties may be associated with poor auditory discrimination. Difficulties with expressive grammar are occurring in the context of severe speech output disorders. NWR deficits are associated with speech production difficulties.

However, it has not been possible to confirm a number of the predictions that were made either for the group as a whole, or for individuals. The model that emerged from the findings within the control group, does not explain the patterns of performance in these clinical cases. Whilst normative data is important in interpreting the extent of speech, language or STM deficits, it may not be helpful in predicting how these skills will develop in children with speech and language impairments. Such children are unlikely to be following normal developmental patterns, given that

mechanisms important for the development of speech, language and STM are impaired from the earliest stages. Rather, individual paths of development might be followed that are dependent on the particular pattern and severity of impairments, and on cognitive skills, language and educational experiences and the emergence of individual compensatory mechanisms. (Karmiloff-Smith, 1998). This will result in individual profiles of performance across tasks.

7.7 CONCLUSION

This study has collected a wide range of data from individuals with different speech and language processing difficulties, at two time points. It is, therefore, a more detailed study of the pattern of performance in such children than have been reported so far. Studies have investigated speech, language and STM skills in groups of children, but these groups tend to be heterogeneous in nature, and it is unlikely that clear, robust, replicable findings will emerge. Published studies of single individuals can not portray the diversity of associations that will be encountered.

The significant relationships between auditory discrimination and STM and language skills do not seem to apply to children with speech and / or language difficulty, Rather individual profiles of speech processing, language and STM have emerged. Some patterns of performance common to two or more children have been described, however, these may only be applicable to children with very specific patterns of speech processing deficit.

CHAPTER 8
CONCLUDING DISCUSSION

8.1 INTRODUCTION

The aim of this thesis has been to explore relationships between short term memory (STM), speech processing skills and language in normal and atypical development. Reviews of the literature identified associations between STM and language development and suggested that speech input and output processing skills might be implicated in the development of STM. Experiment 1 (Chapter 3) examined different measures of speech input and output skills. Non-word repetition (NWR) has been used as a measure of phonological short-term memory (PSTM), and Experiment 2 (Chapter 4) investigated the speech processing skills that might be implicated in NWR performance. In Experiment 3 (Chapter 5), the speech processing skills required for different STM tasks, in which words were recalled, were analysed, and their effect on performance investigated.

Experiment 4 (Chapter 6) explored relationships between STM, NWR, speech processing skills and language development in normal children. A model was proposed that identified significant relationships between auditory discrimination and STM, between auditory discrimination and receptive language development, and between STM and grammatical development. A series of individual case studies of children with a range of speech and / or language difficulties was carried out in Experiment 5 (Chapter 7). The relationships between auditory discrimination, STM and language skills, identified in normal children, were examined in relation to clinical cases.

This chapter will review the findings from the experiments carried out in this thesis. Directions for future research will be discussed.

8.2 INDICATIONS FROM PREVIOUS RESEARCH

A review of the literature showed significant relationships between STM capacity and language development. The nature of these relationships was not clear. Some studies used word and digit span to measure STM skills, but other studies have used NWR as the measure of STM. There has been some debate about whether NWR is a direct measure of STM. Accurate NWR relies on many levels of speech input and output processing, and performance on NWR may also be affected by stored linguistic knowledge, in the form of lexical representation. The phonological loop of the working memory (WM) model (Baddeley & Hitch, 1974) is implicated in STM for words and its functioning appears to rely on some aspects of speech processing. Adams and Gathercole (2000) suggest that STM and language development share some common processes. Consideration should be given to the argument that the efficacy of speech processing skills may underpin relationships between STM and NWR and language development.

Speech processing models (such as Stackhouse & Wells, 1997) allow us to delineate between speech input and output processing and lexical representation. Evaluation of previous STM research suggested that many aspects of speech processing are implicated in STM development and function. For example, associations between speech rate, identification time and word familiarity and STM capacity, and functions such as sub-vocal rehearsal, suggest involvement of all levels of speech processing. Some researchers suggest that the STM system can not be considered as separate from the speech processing system (Snowling & Hulme, 1994, Gathercole

& Martin, 1996). STM development has also been associated with more global cognitive processing, in particular speed and efficiency (Cowan, 1999).

8.3 SPEECH PROCESSING SKILLS

8.3.i Auditory Discrimination and Speech Production

In order to investigate relationships between speech processing skills and STM in more depth, measures of speech processing skills need to be defined. A range of tasks have been used in research and in clinical practice to assess the accuracy of auditory discrimination and speech production skills. These tasks can be evaluated within a psycholinguistic framework (Stackhouse & Wells, 1997) to consider which levels of speech processing are implicated in successful performance. Experiment 1, reported in Chapter 3, demonstrates how performance on different speech processing tasks changes between the ages of 3 and 7 years. There are significant interactions between speech production task scores at different ages. These suggest that as children grow older, their performance is less influenced by bottom-up processing skills and more reliant on lexical representations. This study has allowed a mapping of the developing speech processing system, providing evidence that the expanding store of lexical representations becomes a more active partner in speech processing, once a child reaches the age of 4 – 5 years. Although there is some commonality in performance on both input and output tasks, findings do suggest that there is some independence of functioning between input and output speech processing.

8.3.ii Non-Word Repetition

One focus of this thesis has been to evaluate the NWR task. This has been used in the STM research as a measure of phonological short-term memory. A standardised assessment procedure, the Children's Test of Non-word Repetition (Gathercole et al., 1994b), has been published. However, within the psycholinguistic literature, and in the assessment of children with speech and language difficulties, NWR has been used as a measure of speech output processing, that gives insight into a child's motor programming skills in particular (e.g. Stackhouse & Wells, 1997). These two uses of the NWR task were examined in Chapter 4. Experiment 2 showed that accuracy of NWR was significantly correlated with accuracy of performance on other speech input and output processing measures. This suggests cautious interpretation of the findings of studies that show associations between STM, language and other skills in development, where the measure of phonological short-term memory is NWR. Consideration should be given to whether these associations arise from common influences of speech processing, instead of, or as well as, phonological short-term memory capacity.

8.4 SHORT TERM MEMORY TASKS AND STIMULI

8.4.i STM Tasks

Different combinations of presentation and response modalities can be used in designing tasks to measure recall of lists of words. Such a task can use spoken stimuli, in which case, speech input processing skills will play a part in performance, and spoken responses, in which case speech output processing skills will affect performance.

In Experiment 3, reported in Chapter 5, three different STM paradigms were described and analysed. These compared Spoken Input - Spoken Output with Spoken Input - Picture-pointing Output and Picture Input - Spoken Output. In the literature these different input mechanisms have been used to explore ages at which children use phonological coding of picture material (e.g. Hitch et al., 1989a). Research findings have suggested that younger children do not use the sub-vocal rehearsal process to transfer picture material into a phonological code or to rehearse material in the phonological store (e.g. Gathercole et al., 1994a). In this study these task paradigms were considered to demonstrate different levels of speech processing. Children aged 4 and 5 years showed differential performance across three STM tasks. At both ages, when presentation of the stimuli was spoken, the children were able to recall significantly more stimuli when they pointed to pictures than when they repeated the list of words. 4 year-old children recalled least stimuli when the stimuli were presented as pictures for spoken recall. This may have reflected a difficulty in coding the pictures phonologically. However, at 5 years of age, there is little difference in performance when input is pictorial or spoken. The findings of significant differences in recall for either spoken vs. picture input and spoken vs. picture-pointing response suggest that speech processing skills may have some effect on STM performance.

8.4.ii STM Stimuli

The effect of word length of stimuli on STM recall is well documented (e.g. Baddeley et al., 1975). Fewer multisyllabic words can be recalled than 1 or 2 syllable words. The research has traditionally suggested that the articulatory durations of the words to be recalled are responsible for this effect. This has been interpreted in the light of research findings into the effects of speech rate on STM capacity, and hypotheses about the sub-vocal

rehearsal mechanism of the phonological loop. It is hypothesised that fewer long words can be recalled because they take longer to say, each word takes up more of the capacity within of the sub-vocal rehearsal, and so the whole list cannot be rehearsed as effectively as short words. As mentioned above, in Section 8.4.i, there is some doubt over whether young children use the sub-vocal rehearsal mechanism to rehearse material in the phonological store. If they do not, then it would be difficult to explain word length effects (which have been found in children's recall of spoken material, e.g. Hulme et al. (1984)) in terms of the longer articulatory duration of longer words.

More recently this account has been disputed (e.g. Lovatt et al., 2000) with evidence that word length effects arise from the phonological complexity of the material to be recalled. In Experiment 1, word length effects were found on the production of the single word stimuli material in naming, word repetition and non-word repetition. The maximum length of words presented for repetition was 3 to 4 syllables. As a mean word span of 3-4 single syllable words has been found in children aged 5 years (Hulme & Tordoff, 1989, Henry & Millar, 1991). This suggests that accuracy of response may be affected by the amount of phonological material to be processed, rather than by some aspect of temporary storage of the material.

In Experiment 3, the spoken durations of words to be included in lists for recall were carefully timed. Sets of stimuli were devised in which phonologically simple words (i.e. CVC) were matched with complex words (i.e. CCVC or CVCC) for spoken duration. Children recalled significantly fewer of the words in the complex lists than in the simple lists. That is, children could remember more of the words that contained fewer phonemes. As the simple and complex word lists had been matched for

spoken duration, perhaps the word length effect requires some reinterpretation. Perhaps fewer long words are recalled because more units of phonological information (i.e. phonemes or syllables) have to be decoded and produced. On this view the word length effect would arise from limitations in speech processing efficiency, rather than in sub-vocal rehearsal. Indeed, some researchers have argued that the word-length effect occurs during spoken output (Cowan et al., 1992, Henry, 1991b). The data collected in Experiment 3 suggested a trend for the effect of phonological complexity to be smallest for the STM task in which output is by picture-pointing. The word-length effect in children may be the result of limitations of speech output processing efficiency. These hypotheses cannot be extrapolated to explain word-length effects in older children or adults, as different mechanisms may come into play as the STM and speech processing systems mature.

8.5 SPEECH PROCESSING, STM AND LANGUAGE DEVELOPMENT

The research literature suggests close relationships between STM and language development and STM and speech processing skills. The nature of the relationships between STM and language development has not been satisfactorily explained. One of the hypotheses put forward is that the primary function of the phonological loop is to support language learning (Baddeley et al., 1998). However, as discussed in Section 8.3.ii above, some caution is needed in interpreting the results of studies where NWR is the STM measure used. Key to this debate is the way in which the phonological loop is considered to function, and whether it is an independent system or an integral part of the speech processing system.

The central hypothesis explored in this thesis is that STM and language development may be closely associated because they both rely on the accuracy and efficiency of speech processing skills.

The longitudinal study reported in Chapter 6, allowed some exploration of the complex concurrent and predictive relationships found in development from 4 to 5 years of age. Suspicions about the use of the NWR task in STM research were confirmed. Accuracy of NWR was not significantly associated with either STM or performance on language measures. However, speech production skills did significantly predict NWR. It may, therefore, be misleading to suggest that findings of associations between NWR and language development reflect relationships between STM and language development. Such associations may arise from a different set of mechanisms, for example from relationships between speech output processing and language development.

However, speech input, not output, processing skills were found to support aspects of language development. Auditory discrimination scores significantly predicted the development of receptive language skills. Speech production scores did not predict performance on any of the language measures used. Auditory discrimination was also found to significantly predict STM development, as were some measures of speech processing speeds. STM significantly predicted grammatical aspects of language development. These findings are age-specific and can only be interpreted for the stage in development that was being investigated, i.e. changes that are occurring between the ages of 4 to 6 years. Other relationships may be significant and predictive for younger or older children. For example, accuracy of NWR at the age of 3 years may be a

better predictor of language development at 4 or 5 years of age, than it was found to be at the ages investigated in this experiment.

This study took a more fine-grained approach to this area of research to enable the complex web of relationships between STM, speech processing and language development to be explored. Tasks of speech processing and language were selected to tap very specific functions, and analyses examined relationships with particular aspects of language. Although the sample size was small, the range of measures used was very comprehensive. Tasks were compiled with careful consideration to allow comparison of different processing demands on skills in development. The proposed model attributes clear, predictive power to auditory discrimination and STM skills for language development at the age of 5 years. It challenges 'simplistic' conceptualisations of the relationship between phonological short-term memory and language development, by providing a comprehensive picture, that brings together the contributions of psycholinguistic and memory factors.

8.6 SPEECH PROCESSING, STM AND LANGUAGE IN CLINICAL CASES

Earlier research has investigated NWR and STM deficits in children with speech and / or language difficulties. Relationships between STM deficits and SLI have been interpreted to imply direct causation (e.g. Gathercole & Baddeley, 1990b). In some of these studies NWR has been used as the measure of phonological short-term memory. Dollaghan and Campbell (1998) have found that NWR scores absolutely distinguish SLI children from non-language impaired controls, at an individual level, with no overlap between the 2 groups. NWR deficits, therefore, appear to be the

cleanest indictor of SLI. Bishop et al. (1996) reinforce this argument by proposing that NWR scores could be phenotypic marker for genetically transmitted SLI.

However, analyses of the normative data in Experiment 4 (Chapter 6) suggests that the relationship between NWR and STM is complex, and may be mediated by a third factor. In Experiment 5 (Chapter 7) longitudinal data was presented from a series of individual case studies. Children with a range of speech and / or language difficulties were included. The analyses of case data considered whether either NWR or STM skills showed significant deficits relative to receptive language levels. Where NWR deficits were observed, these were associated with speech production difficulties and not with reduced STM. This accords with the finding that NWR was significantly predicted by speech production skills in the control data. It also suggests that NWR and STM are not necessarily equivalent measures.

Generally, STM capacity was in line with the level of receptive language shown by the children. Van der Lely and Howard (1993) reported similar findings for their group of children with SLI. It could be argued that STM capacity is limited by speech / language processing skills, but that is only one possible interpretation. STM or receptive language deficits were not always demonstrated in these cases, because the design used for this study compared data to a language-matched group. What is clear is that STM and receptive language skills seem to be developing on a par with each other.

The patterns of predictive relationships between STM, speech processing and language that were found in the normally developing children, were not clearly confirmed in the children with speech and language difficulty.

Observation of the patterns of stability and change in individual cases showed that developmental trajectories vary in a way that is individually distinctive. While progress in some individuals conforms to normative patterns, as defined by receptive language age, other cases are very divergent. For example, dramatic improvement is demonstrated for one or more skill areas, but in other cases deficits are accumulating. Common patterns of development did not often occur, even in children with a similar clinical diagnosis. It seems, therefore, that individual profiles of deficit are not easily predictable. Rather, each child with a speech and / or language difficulty is presenting with a, possibly, unique pattern of performance and a route through development which is governed by individual patterns of deficits and compensatory strategies.

The body of research in the field of speech and language impairment depends on findings from a single time-point, or on long-term follow-up. The findings of this study suggest that short-term longitudinal measurement is essential to understanding individual differences and to providing a comprehensive answer to cause and effect in developmental relationships and in predicting outcomes.

8.7 FUTURE DIRECTIONS

8.7.i Models of STM development

Much of the research in the field of STM development has been interpreted in terms of the WM model (Baddeley & Hitch, 1974). It may be time for some re-evaluation of the nature of the phonological loop, and its role in development. It has more recently been argued that there is not a distinct PSTM system, but rather speech processing skills are implicated. Whilst interactions between speech input and output processing and lexical

representations have been modelled (e.g. Stackhouse & Wells, 1997), hypotheses have not yet been generated about how a temporary storage facility might fit into this system.

Further research may allow hypotheses about the functioning of the phonological loop to be clarified. This may enable development of new ideas about how temporary storage mechanisms operate within a speech processing system. In Experiment 3 (Chapter 5) the word length effect was re-examined from the perspective of findings of effects of phonological complexity, when word length, in terms of syllables, and spoken duration was controlled. The findings indicate that it may be the amount of information to be retained, i.e. number of phonemes, that affects recall. However, this warrants further investigation. Stimuli lists, matched for spoken duration, may be used that systematically vary combinations of numbers of phonemes and syllables, to examine which phonological unit is influential. For example, stimuli lists may be matched for number of phonemes, but with a different number of syllables, or matched for the number of syllables, but with different numbers of phonemes.

The role of sub-vocal rehearsal in children's recall is unclear. It has been argued that this mechanism is not used in younger children (Gathercole et al., 1994a). Much research has focussed on children's recall of picture material. Within the framework of the current study, more evaluation of the strategies used in completing the Picture Input-Spoken Output task may be useful. For instance, some children spontaneously named the pictures as they were presented. If naming the pictures aided recall, this would suggest that phonological coding and possibly sub-vocal rehearsal are supporting performance. If it does not aid recall, then phonological coding of the material may not be a key factor in recall. It would also be interesting to

observe the ages at which children tend to spontaneously either overtly or silently name pictures presented for recall, and to see if children with disorders differ in the age at which this occurs. This would allow a developmental pattern, that may or may not be linked with sub-vocal rehearsal, to be established and to test hypotheses about the use, or non-use of phonological coding in disorder.

8.7.ii The Development of STM and Language

The fine-grained approach used in task selection in Experiment 4 (Chapter 6) allowed evaluation of the specific nature of relationships between STM, speech processing and language development, and the longitudinal design allowed predictive relationships to be explored. The data collected was used to tentatively model predictive relationships between STM, speech processing and language development. However, it has already been acknowledged that the sample size was small, and this limited the statistical analyses that could be carried out, and the strength with which findings could be interpreted. A larger sample-size, would allow more sophisticated statistical modelling techniques to be used, such as structural equation modelling. As data was only collected from children between the ages of 4;06 and 6 years, the associations found could only be ascribed to a limited developmental stage.

In order to confirm, or refine, the significant predictive relationships found in this study, in normally developing children, a similar test battery could be used to collect data from larger groups of children. It may be useful to include a serial order STM task in the test battery, to see whether sequential processing skills are key to the relationships between STM and language, and STM and NWR, that have been reported in the literature. This would provide further evidence for the nature of the cognitive processes that may

be important for the development of STM and language skills. The first data set could be collected at an earlier stage in development, perhaps from children 2;06 to 3 years-old, and a longitudinal study could be extended over a longer period of time. This would allow associations that may be specific to different stages of development to be examined.

8.7.iii STM deficits and Speech and Language Disorder

The data collected in Experiment 5 (Chapter 7) from the individual children with speech and language difficulties, did not confirm any common patterns of relationships between STM, speech and language development, or of the nature of relationships between STM deficit and speech or language disorder. However, the finding of individual patterns of skills and development suggests that an individual case study approach is a sound way to investigate relationships in disorder. If profile data is collected from sufficient numbers of cases, and symptoms and processing deficits carefully analysed, patterns may begin to emerge. In this data, for example, ZC and MG presented with very similar profiles.

The design of the study prevented examination of some hypotheses about the relationship between STM deficits and SLI. The comparison with receptive language-matched data obscured deficits in STM and receptive language that might be present when chronological age is considered. Further investigation of individual case studies may benefit from the use of both language- and age-matched data. This would enable areas of deficit to be more clearly identified. Some researchers have argued for a serial order deficit in STM in SLI (Kushnir & Blake, 1996). Perhaps sequential processing is impaired and underpinning STM deficits and SLI. The use of a free recall scoring system for the STM tasks meant that these hypotheses

could not be examined in this study, but this is an area that could be fruitfully explored by collecting serial order STM data.

A number of cases showed a co-occurrence of speech production difficulties and poor expressive grammar. In fact, all the cases that showed expressive grammar also had speech production difficulties. Although speech production did not show any significant relationship with expressive grammar in the normal children, this relationship may form part of a common pattern in disordered development. There is, therefore, a need for this to be evaluated further, and a range of variables considered as not all the children with speech production difficulties had poor expressive vocabulary.

If speech processing skills are considered to underpin STM and language development then useful insight into the mechanisms by which these skills evolve might be gained by investigating STM and language skills in children with different profiles of known speech processing deficit. More detailed analysis can be carried out of children's speech processing profiles using the psycholinguistic framework (Stackhouse & Wells, 1997). This will allow processing deficits to be more specifically located than was possible in this study, which focussed on distinguishing speech input from speech output in general terms. If particular levels of speech processing deficit can be identified and associated with certain patterns of STM and language development, then further hypotheses can be generated about these complex relationships, for testing with both normal and disordered populations.

8.7.iv Measuring speech processing and STM skills

The experiments within this thesis used carefully designed and selected measures of STM and speech processing that were finely-tuned to identify specific levels of speech processing involved. As discussed in Chapter 3, it is difficult to design auditory discrimination tasks that are accessible to young children, in which attention and cognitive demands do not interfere with performance. Some consideration needs to be given to the way in which such tasks are presented. At the other end of the age group studied, some tasks of both auditory discrimination and speech production showed ceiling effects. It may be possible to design stimuli lists that are more sensitive to individual differences in older children, or to look for developmental differences in response times that may be significant for older children.

During data collection problems were experienced with presentation of stimuli in less that ideal situations of background noise and distraction. It was also difficult and time-consuming to precisely measure timings of speech rate and response time from the tape-recordings that had been made. Greater use could be made of technology now available. For instance, stimuli for discrimination, repetition or recall could be recorded using laboratory facilities to present more consistent and clearer speech signals. Stimuli could be presented, and responses collected, using software on a portable computer. A carefully-designed visual display on the computer may aid in maintaining the child's attention control. It may also be possible for software to be developed that would train younger children to complete auditory discrimination tasks such as same/different. If stimuli are delivered and responses recorded by the same system, more accurate response times can be measured, possibly relatively automatically.

The research literature suggests some difficulty in untangling speech processing and STM systems. Either very close relationships exist between these functions, or they are both mechanisms within the same system. In order to address hypotheses about these relationships it will be important for further research to carry out a careful analysis of the STM requirements of different speech processing tasks. For example, performance may be affected by stimuli lists of different word lengths, or by the number of stimuli presented within a task. For auditory discrimination task paradigms, a same / different task will present 2 spoken stimuli, an ABX task may present 3, and an 'odd one out' task may present as many as 4 spoken stimuli. It will be equally important to evaluate the speech processing demands within different STM tasks that might be used. For example, the speech processing levels activated will differ if stimuli are non-words rather than words, or if presentation is visual rather than verbal. Another way in which performance might be usefully compared is to contrast a list of several stimuli with single word stimuli for same paradigm. For example, comparing naming of single pictures with performance on a Picture Input-Spoken Output fixed list or increasing span task, might allow contributions of speech processing and STM to performance to be more clearly identified.

8.8 CONCLUSION

This field of study has proved to be most complex. The research literature suggests close relationships between STM, speech and language in normal and atypical development. There are many hypotheses about the nature of these relationships. A key focus in this thesis has been to investigate relationships between STM and language development from the perspective of the effect of underlying speech processing skills on both

these mechanisms. Findings of significant predictive relationships between auditory discrimination and STM, and between auditory discrimination, STM and language, in normal development, have been described. Clinical case studies have shown that disordered children follow individual, possibly even unique, paths through development. These can only be understood through short-interval, longitudinal observation, based on appropriate longitudinal, normative data.

A number of ways have been suggested in which similar studies could expand these findings. It may also be possible to refine the data that is collected, with additional measures, and more carefully controlled design and presentation. The thesis has advocated a fine-grained approach to task selection that will allow very specific hypotheses to be tested and subtle relationships to emerge.

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APPENDIX 1
Experiment 1: Stimuli for Speech output Tasks

Set One

Naming / Word Repetition	Non-word Repetition	Naming/Word Repetition	Non-word Repetition
Practice items:			
Light, Sofa, Sticker book	/saɪp - ˈgɔɹedʒ - ˈnaɪzpəʊpɪ/		
Test items:			
Brush	/bɹɪʃ/	Plate	/pləʊt/
Sponge	/spændʒ/	Roof	/ɹɔf/
Glove	/glev/	Fish	/feʃ/
Duck	/dæk/	Chair	/tʃi/
Leaf	/lɔf/	Thumb	/θɒm/
Sock	/sɔk/	Sandwich	/ˈsɪmwədʒ/
Cat	/ket/	Toilet	/ˈteɪlət/
Book	/bɔk/	Money	/ˈmenə/
Torch	/tutʃ/	Feather	/ˈfæðɪ/
Mouse	/mɔɪs/	Yellow	/ˈjæləɪ/
Knife	/nəʊf/	Kitchen	/ˈkɒtʃən/
Snake	/snaɪk/	Ladder	/ˈledɪ/
Train	/tɹɔɪn/	Flower	/ˈfluwɪ/
Van	/vɪn/	Dustbin	/ˈdæsbən/
Watch	/wʊtʃ/	Jelly	/ˈdʒʌlə/

Set Two

Tractor	/ˈtɹektɪ/	Umbrella	/æmˈbɹælɪ/
Fishing	/ˈfɒʃɪŋ/	Helicopter	/ˈhɪləkæptɪ/
Biscuit	/ˈbɒskət/	Kangaroo	/ˈkɒŋgɪɹɑ/
Scooter	/ˈskitə/	Television	/ˈtʊləvæʒən/
Parrot	/ˈpʌɹɪt/	Hospital	/ˈhæspətɪl/
Seesaw	/ˈsɑsi/	Telephone	/ˈtɒləfaɪn/
Slipper	/ˈslɔpə/	Parachute	/ˈpeɹəʃit/
Sausage	/ˈsesədʒ/	Butterfly	/ˈbætəfləʊ/
Guitar	/geˈtɔ/	Computer	/kemˈpjaʊtɪ/
Spider	/ˈspeɪdɪ/	Roundabout	/ˈɹəʊndəbaɪt/
Caterpillar	/ˈkɪtəpælə/	Hairdresser	/ˈhɔɪdɹæsɪ/
Spaghetti	/spʌˈgɪtə/	Aeroplane	/ˈɒɹəpləʊn/
Elephant	/ˈælɪfɒnt/	Pyjamas	/pɪˈdʒɔmɪz/
Caravan	/ˈkʌɹəvɪn/	Hamburger	/ˈhɪmbɑgɪ/
Crocodile	/ˈkɹɪkədaʊl/	Dinosaur	/ˈdeɪnɪsɑ/

APPENDIX 2
Experiment 1: Stimuli for Auditory Discrimination Picture Task

Set One

Picture	Stimulus	Picture	Stimulus
Practice items			
table	chair, table,	house	/spaʊs/ house
	/sleɪbl̩/ /teɪʃl̩/		/faʊs/ /haʊf/
	table		house
Test items			
brush	brush	plate	/peɪt/
	brush		/peɪt/
	/bɹʌs/		plate
sponge	/spʌndz/	roof	roof
	sponge		roof
	sponge		/ɹus/
glove	/glʌb/	fish	/vɪʃ/
	glove		fish
duck	/gʌk/	chair	chair
	duck		/tsɛə/
	/gʌk/	thumb	/ðʌm/
leaf	/jif/		thumb
	leaf	sandwich	/ˈfæmwɪdʒ/
sock	sock		sandwich
	/zɒk/		/ˈfæmwɪdʒ/
	sock	toilet	/ˈdɔɪlət/
cat	/tæt/		toilet
	cat	money	/ˈnʌmɪ/
	/tæt/		money
book	book	feather	feather
	/mʊk/		/ˈðefə/
torch	/dɔtʃ/	yellow	yellow
	torch		/ˈlejəʊ/
mouse	/maʊt/		yellow
	mouse	kitchen	kitchen
knife	knife		/ˈgɪtʃən/
	/maɪf/	ladder	ladder
	/maɪf/		/ˈjædə/
snake	snake	flower	/ˈslaʊwə/
	/neɪk/		flower
train	/teɪn/		/ˈslaʊwə/
	train	dustbin	dustbin
van	/zæn/		/ˈbʌsdɪn/
	van	jelly	jelly
	van		/ˈdzelɪ/
watch	/ɹɒtʃ/		jelly
	watch		

Set Two

Picture	Stimulus	Picture	Stimulus
tractor	/ˈdɹæktə/	umbrella	umbrella
	tractor		/ʌmˈbleɹə/
fishing	fishing	helicopter	helicopter
	fishing		helicopter
	/ˈʃɪfɪŋ/		/ˈhelɪtɒpkə/
biscuit	/ˈbɪksɪt/	kangaroo	/ˈgæŋkəɹu/
	/ˈbɪksɪt/		kangaroo
	biscuit	television	/ˈtevəlɪʒən/
scooter	/ˈstukə/		/ˈtevəlɪʒən/
	scooter		television
	/ˈstukə/	hospital	/ˈhɒstɪpəl/
parrot	/ˈbæɹət/		hospital
	parrot	telephone	telephone
seesaw	/ˈsitɔ/		/ˈdelɪfəʊn/
	seesaw		/ˈdelɪfəʊn/
	seesaw	parachute	/ˈpæɹəsut/
slipper	/ˈlɪpə/		parachute
	slipper	butterfly	/ˈbʌtəfaɪ/
sausage	sausage		butterfly
	/ˈsɒdʒɪs/		butterfly
	/ˈsɒdʒɪs/	computer	computer
guitar	/tɪˈgɑ/		/gəmˈpjutə/
	guitar		computer
spider	spider	roundabout	/ˈwaʊndəbaʊt/
	/ˈstaɪbə/		roundabout
	spider	hairdresser	hairdresser
caterpillar	caterpillar		/ˈhɛədɹetə/
	/ˈkæpətɪlə/	aeroplane	/ˈeəɹəpɹeɪn/
	caterpillar		aeroplane
spaghetti	/gəˈspetɪ/	pyjamas	pyjamas
	spaghetti		/pəˈdʒɑbəz/
	spaghetti		/pəˈdʒɑbəz/
elephant	/ˈefɪlənt/	hamburger	/ˈhæmbɜdə/
	elephant		Hamburger
caravan	/ˈkævəɹæn/	dinosaur	/ˈdaɪnəzɔ/
	caravan		/ˈdaɪnəzɔ/
	/ˈkævəɹæn/		dinosaur
crocodile	/ˈkɹɒdəkaɪl/		
	crocodile		

APPENDIX 3
Experiment 1: Stimuli for Auditory Discrimination Same / Different Task (after Bridgeman & Snowling, 1988)

Non-word pairs	Word pairs
Practice items	
/vɒs - vɒt/	
/fest - fets/	
/vɒst - vɒts/	
/tet - tet/	
Test items	
/kest - kets/	kit – kit
/bleɪs - bleɪt/	hits – hissed
/zet - zet/	messed – messed
/fɒt - fɒs/	guess – get
/kes - ket/	race – rate
/dɪts - dɪst/	mitts – missed
/vɪt - vɪs/	plate – place
/pəʊts - pəʊts/	guessed – gets
/zets - zets/	kissed – kissed
/fɒts - fɒst/	rates – raced
/vɪts - vɪst/	tots – tossed
/bɪs - bɪs/	tot – toss
/jeɪts - jeɪst/	miss – mitt
/dɪt - dɪs/	hit – hiss
/pəʊt - pəʊt/	goats – goats
/jeɪs - jeɪt/	met - met
/bɪst - bɪst/	placed - plates
/bleɪst - bleɪts/	goat - goat

Appendix 4
Experiment 1: Stimuli for ABX Task

Set One

Word from which stimulus derived	A stimulus	B stimulus	X stimulus
Practice items	/səʊf/	/təʊf/	/səʊf/
	/spin/	/stin/	/stin/
	/ˈglɪzəs/	/ˈklɪzəs/	/ˈklɪzəs/
	/gɹɪb/	/sɪb/	/gɹɪb/
	/baʊg/	/baʊf/	/baʊf/
	/spəʊd/	/pəʊd/	/spəʊd/
Test items			
plate	/pəʊt/	/pləʊt/	/pləʊt/
sock	/sɔk/	/zɔk/	/zɔk/
van	/vɪn/	/zɪn/	/vɪn/
roof	/ɹɔf/	/ɹɔs/	/ɹɔs/
snake	/naɪk/	/snaɪk/	/naɪk/
train	/tɔɪn/	/trɔɪn/	/tɔɪn/
thumb	/ðɒm/	/θɒm/	/θɒm/
fish	/veʃ/	/feʃ/	/feʃ/
watch	/wʊtʃ/	/rʊtʃ/	/wʊtʃ/
torch	/dutʃ/	/tutʃ/	/tutʃ/
brush	/bɹɪs/	/bɹɪʃ/	/bɹɪʃ/
mouse	/mɔɪt/	/mɔɪs/	/mɔɪt/
cat	/tet/	/ket/	/ket/
sponge	/spændʒ/	/spændz/	/spændz/
knife	/məʊf/	/nəʊf/	/məʊf/
leaf	/lɔf/	/jɔf/	/lɔf/
book	/mɔk/	/bɔk/	/bɔk/
duck	/dæk/	/gæk/	/dæk/
chair	/tʃi/	/tsi/	/tʃi/
glove	/gleb/	/glev/	/gleb/
parrot	/ˈpʌɹɪt/	/ˈbʌɹɪt/	/ˈbʌɹɪt/
spider	/ˈspeɪdɪ/	/ˈsteɪbɪ/	/ˈsteɪbɪ/
biscuit	/ˈbɒksət/	/ˈbɒskət/	/ˈbɒskət/
toilet	/ˈdeɪlət/	/ˈteɪlət/	/ˈdeɪlət/
dustbin	/ˈdæsbən/	/ˈbæsdən/	/ˈbæsdən/
jelly	/ˈdzʌlə/	/ˈdʒʌlə/	/ˈdzʌlə/
seesaw	/ˈsɑsi/	/ˈsɑti/	/ˈsɑti/
tractor	/ˈdɹektɪ/	/ˈtɹektɪ/	/ˈtɹektɪ/
flower	/ˈfluwɪ/	/ˈsluwɪ/	/ˈsluwɪ/
fishing	/ˈʃɒfɪŋ/	/ˈfɒʃɪŋ/	/ˈʃɒfɪŋ/

Set Two

Word from which stimulus derived	A stimulus	B stimulus	X stimulus
sandwich	/ˈsɪmwədʒ/	/ˈfɪmwedʒ/	/ˈsɪmwədʒ/
kitchen	/ˈkɒtʃən/	/ˈgɒtʃən/	/ˈkɒtʃən/
feather	/ˈfæðɪ/	/ˈðæfɪ/	/ˈfæðɪ/
money	/ˈnemə/	/ˈmenə/	/ˈmenə/
ladder	/ˈjedɪ/	/ˈledɪ/	/ˈjedɪ/
guitar	/teˈgɔ/	/geˈtɔ/	/geˈtɔ/
scooter	/ˈstikə/	/ˈskitə/	/ˈskitə/
yellow	/ˈlæjɔɪ/	/ˈjælɔɪ/	/ˈlæjɔɪ/
sausage	/ˈsedʒəs/	/ˈsesədʒ/	/ˈsedʒəs/
slipper	/ˈslɔpə/	/ˈlɔpə/	/ˈslɔpə/
butterfly	/ˈbætəfləʊ/	/ˈbætəfəʊ/	/ˈbætəfləʊ/
dinosaur	/ˈdeɪnɪzɑ/	/ˈdeɪnɪsɑ/	/ˈdeɪnɪsɑ/
hairdresser	/ˈhɔɪdɹæsɪ/	/ˈhɔɪdɹætɪ/	/ˈhɔɪdɹætɪ/
spaghetti	/spʌˈgɪtə/	/gʌsˈpɪtə/	/spʌˈgɪtə/
parachute	/ˈpeɹəsit/	/ˈpeɹəʃit/	/ˈpeɹəʃit/
crocodile	/ˈkɹɪdəkaʊl/	/ˈkɹɪkədaʊl/	/ˈkɹɪdəkaʊl/
elephant	/ˈæfɪlɒnt/	/ˈælɪfɒnt/	/ˈæfɪlɒnt/
aeroplane	/ˈɒɹəpɹəʊn/	/ˈɒɹəpləʊn/	/ˈɒɹəpɹəʊn/
pyjamas	/pɪˈdʒɔmɪz/	/pɪˈdʒɔbɪz/	/pɪˈdʒɔbɪz/
telephone	/ˈdɒləfaɪn/	/ˈtɒləfaɪn/	/ˈdɒləfaɪn/
hamburger	/ˈhɪmbɑgɪ/	/ˈhɪmbɑdɪ/	/ˈhɪmbɑdɪ/
roundabout	/ˈɹəʊndəbaɪt/	/ˈwəʊndəbaɪt/	/ˈɹəʊndəbaɪt/
caravan	/ˈkʌvɒɹɪn/	/kʌɹɒvɪn/	/kʌɹɒvɪn/
caterpillar	/ˈkɪtəpælə/	/ˈkɪpətælə/	/ˈkɪpətælə/
computer	/gemˈpjaʊtɪ/	/kemˈpjɑʊtɪ/	/kemˈpjɑʊtɪ/
helicopter	/ˈhɪlətæpkə/	/ˈhɪləkæptə/	/ˈhɪlətæpkə/
hospital	/ˈhæstʌpɪl/	/ˈhæspʌtɪl/	/ˈhæspʌtɪl/
umbrella	/ˈæmbɹælɪ/	/ˈæmblæɹɪ/	/ˈæmblæɹɪ/
kangaroo	/ˈkɒŋgɪɹɑ/	/ˈgɒŋkɪɹɑ/	/ˈkɒŋgɪɹɑ/
television	/ˈtʊvɒlæʒn̩/	/ˈtʊlɒvæʒn̩/	/ˈtʊlɒvæʒn̩/

Appendix 5
Experiment 3: Stimuli for T1 Short-term Memory Tasks

T1 Spoken Input-Spoken Output

Practice Items	soap	cage	worm	
	bell	road	case	wool
Test Items	clock	bread	spoon	crab
	tap	bus	sock	leaf
	drum	frog	tent	bridge
	cup	ring	shop	horse
	plug	brick	box	flag
	Girl	pig	fork	cheese

T1 Spoken Input-Picture pointing Output

Practice Items	bear	saw	bath	
	bed	doll	church	cake
Test Items	flag	box	plug	brick
	cheese	fork	girl	pig
	bread	spoon	clock	crab
	bus	sock	tap	leaf
	frog	bridge	drum	tent
	ring	horse	cup	shop

T1 Picture Input-Spoken Output

Practice Items	book	duck	shoe	
	chair	knife	ball	key
Test Items	tent	drum	frog	bridge
	shop	cup	ring	horse
	box	brick	plug	flag
	fork	pig	girl	cheese
	bread	crab	clock	spoon
	bus	leaf	tap	sock

Appendix 6
Experiment 3: Stimuli for T2 Short term Memory Tasks

T2 Spoken Input-Spoken Output

Practice Items	soap	cage	worm	school	
	bell	road	case	wool	pear
Test Items	cup	ring	cheese	girl	horse
	drum	fox	sweet	plug	bridge
	knife	bus	shell	sock	leaf
	frog	bread	box	spoon	crab
	shop	church	pig	fork	tap
	swing	tent	brick	flag	clock

T2 Spoken Input-Picture pointing Output

Practice Items	bath	saw	key	ball	
	bed	doll	plate	cake	shoe
Test Items	pig	tap	church	fork	shop
	brick	clock	tent	flag	swing
	cheese	cup	girl	ring	horse
	sweet	drum	plug	fox	bridge
	shell	bus	knife	leaf	sock
	box	bread	frog	crab	spoon

T2 Picture Input-Spoken Output

Practice Items	chair	ball	key	duck	
	shoe	book	boat	dog	man
Test Items	shell	sock	knife	leaf	bus
	box	spoon	frog	crab	bread
	pig	fork	tap	shop	church
	brick	flag	clock	swing	tent
	girl	cup	cheese	horse	ring
	plug	drum	sweet	bridge	fox

Appendix 7

Experiment 3: Pilot study results

ANOVA table of Task X Complexity

Source of variation	SS	DF	MS	F	Sig of F
Error	58.030	20	2.902		
Task	162.303	2	81.152	27.969	<.001
Error	13.364	10	1.336		
Complexity	13.636	1	13.636	10.204	.01
Task X Complexity	1.091	2	.545	.273	.764

Appendix 8
Experiment 4: Stimuli for speech production tasks at T1 and T2

Stimuli for Naming Task at T1 & T2

T1 List A	T1 List B	T2 List A	T2 List B
Aeroplane	Fish	Aeroplane	Fish
Flower	Butterfly	Flower	Butterfly
Caterpillar	Plate	Caravan	Telephone
Train	Sausage	Caterpillar	Plate
Spider	Guitar	Train	Sausage
Brush	Van	Crocodile	Computer
Tractor	Parachute	Spider	Guitar
Jelly	Snake	Brush	Van
Sponge	Elephant	Helicopter	Roundabout
Pyjamas	Yellow	Tractor	Parachute
Spaghetti	Umbrella	Jelly	Snake
Glove	Slipper	Kangaroo	Hairdresser
		Sponge	Elephant
		Pyjamas	Yellow
		Television	Hamburger
		Spaghetti	Umbrella
		Glove	Slipper
		Hospital	Dinosaur

Stimuli for Word Repetition Task at T1 and T2

T1 List A	T1 List B	T2 List A	T2 List B
Practice items			
Light, Sofa, Sticker-book			
Test items			
Snake	Train	Snake	Train
Guitar	Aeroplane	Guitar	Aeroplane
Van	Tractor	Multitude	Astronomy
Plate	Brush	Van	Tractor
Sausage	Jelly	Plate	Brush
Slipper	Caterpillar	Electricity	Thermometer
Elephant	Spider	Sausage	Jelly
Umbrella	Pyjamas	Slipper	Caterpillar
Butterfly	Sponge	Description	Investigation
Parachute	Flower	Elephant	Spider
Fish	Spaghetti	Umbrella	Pyjamas
Yellow	Glove	Handkerchief	Possession
		Butterfly	Sponge
		Parachute	Flower
		Opportunity	Satisfaction
		Fish	Spaghetti
		Yellow	Glove
		Substitute	Privilege

Stimuli for Non-word Repetition Task at T1 and T2

T1 List A	T1 List B	T2 List A	T2 List B
Practice items			
/saɪp/ /ˈgɔɹedʒ/ /ˈnaɪzpəʊpɪ/			
Test items			
/ˈspeɪdɪ/	/snaɪk/	/tɹɔɪn/	/snaɪk/
/ˈspændʒ/	/ˈsesədʒ/	/ˈɒɹəpləʊn/	/geˈtɔ/
/ˈfluwɪ/	/vɪn/	/ɪsˈtɹænəmɪ/	/ˈmæltɪtʃid/
/tɹɔɪn/	/geˈtɔ/	/ˈtɹektɪ/	/vɪn/
/pɪˈdʒɔmɪz/	/ˈslɔpə/	/bɹɪʃ/	/pləʊt/
/spʌˈgɪtə/	/æmˈbɹælɪ/	/θɪˈmæmʌtɪ/	/ɒlɪkˈtɹæsətɪ/
/ˈkɪtəpælə/	/ˈælifɒnt/	/ˈdʒʌlə/	/ˈsesədʒ/
/ˈɒɹəpləʊn/	/ˈbætəfləʊ/	/ˈkɪtəpælə/	/ˈslɔpə/
/ˈtɹektɪ/	/ˈjæləɪ/	/ɒnˈvæstəguʃn̩/	/dʌsˈkɹɒpʃn̩/
/bɹɪʃ/	/ˈpeɹəʃit/	/ˈspeɪdɪ/	/ˈælifɒnt/
/ˈdʒʌlə/	/feʃ/	/pɪˈdʒɔmɪz/	/æmˈbɹælɪ/
/glev/	/pləʊt/	/pəˈzæʃən/	/ˈheŋkətʃuf/
		/ˈspændʒ/	/ˈbætəfləʊ/
		/ˈfluwɪ/	/ˈpeɹəʃit/
		/sɒtɪsˈfekʃn̩/	/ɪpəˈtʃɑnətɪ/
		/spʌˈgɪtə/	/feʃ/
		/glev/	/ˈjæləɪ/
		/ˈpɹævəlʌdʒ/	/ˈsæbstətʃɔt/

Appendix 9
Experiment 4: Stimuli for Auditory discrimination Picture Task

T1 - Set A

Picture	Stimulus	Picture	Stimulus
Practice Items:			
table	chair	house	house
	table		/faʊs/
	/ˈsleɪbl̩/		/haʊf/
	/ˈteɪʃl̩/		house
	table		
Test items:			
sponge	/spʌndz/	aeroplane	/ˈɛəɹəpɹeɪn/
	sponge		aeroplane
	sponge	tractor	/ˈdɹæktə/
flower	/ˈslaʊwə/		tractor
	flower	brush	brush
	/ˈslaʊwə/		brush
train	/teɪn/		/bɹʌs/
	train	spider	spider
pyjamas	pyjamas		/ˈstaɪbə/
	/pəˈdʒɑbəz/		spider
	/pəˈdʒɑbəz/	glove	/glʌb/
spaghetti	/gəsˈpetɪ/		glove
	spaghetti	jelly	jelly
caterpillar	caterpillar		/ˈdzelɪ/
	/ˈkæpətɪlə/		
	caterpillar		

T1 - Set B

snake	snake	butterfly	/ˈbʌtəfaɪ/
	/neɪk/		butterfly
parachute	/ˈpæɹəsut/		butterfly
	parachute	guitar	/tɪˈgɑ/
sausage	sausage		guitar
	/ˈsɒdʒɪs/	yellow	yellow
	/ˈsɒdʒɪs/		/ˈlejəʊ/
fish	/vɪʃ/		yellow
	fish	slipper	/ˈlɪpə/
	fish		slipper
elephant	/ˈefɪlənt/	plate	/peɪt/
	elephant		/peɪt/
umbrella	umbrella		plate
	/ʌmˈbleɹə/	van	/zæn/
			van
			van

T2 - Set A

Picture	Stimulus	Picture	Stimulus
Practice Items:			
car	/tɑ/	horse	/hɔf/
fork	fork		
Test Items:			
Kangaroo	kangaroo	Helicopter	/ˈhelɪtɒpkə/
Glove	/glʌb/	Aeroplane	aeroplane
Caterpillar	/ˈkæpətɪlə/	Sponge	sponge
Television	television	Flower	/ˈslaʊwə/
Brush	/bɹʌs/	Helicopter	helicopter
Jelly	/ˈdzelɪ/	Spaghetti	/gəsˈpetɪ/
Hospital	/ˈhɒstɪpl̩/	Kangaroo	/ˈgæŋkəɹu/
Jelly	jelly	Caterpillar	caterpillar
Spaghetti	spaghetti	Aeroplane	/ˈeəɹepɹeɪn/
Tractor	tractor	Glove	glove
Television	/ˈtevəlɪʒən/	Brush	brush
Hospital	hospital	Caravan	/ˈkævəɹæn/
Spider	spider	Pyjamas	pyjamas
Pyjamas	/pəˈdʒɑbəz/	Train	train
Sponge	/spʌndz/	Crocodile	crocodile
Flower	flower	Tractor	/ˈdɹæktə/
Train	/teɪn/	Caravan	caravan
Spider	/ˈstaɪbə/	Crocodile	/ˈkɹɒdəkaɪl/

T2 - Set B

Butterfly	butterfly	Van	/zæn/
Dinosaur	/ˈdaɪnəzɔ/	Computer	/gəmˈpjutə/
Fish	fish	Slipper	/ˈlɪpə/
Hairdresser	hairdresser	Dinosaur	dinosaur
Elephant	/ˈefɪlənt/	Parachute	parachute
Telephone	telephone	Umbrella	/ʌmˈbleɹə/
Snake	snake	Guitar	guitar
Butterfly	/ˈbʌtəfaɪ/	Elephant	elephant
Parachute	/ˈpærəsut/	Hamburger	hamburger
Roundabout	roundabout	Telephone	/ˈdelɪfəʊn/
Hairdresser	/ˈheədretə/	Snake	/neɪk/
Yellow	yellow	Slipper	slipper
Fish	/vɪʃ/	Yellow	/ˈlejəʊ/
Guitar	/tɪˈgɑ/	Plate	plate
Sausage	/ˈsɒdʒɪs/	Computer	computer
Umbrella	umbrella	Roundabout	/ˈwaʊndəbaʊt/
Plate	/peɪt/	Hamburger	/ˈhæmbɜdə/
Sausage	sausage	Van	van

Appendix 10
Experiment 4: Stimuli for Auditory Discrimination Same / Different Task

T1

	List A	List B
Practice Items	Child's name	/fest - fest/
	tots - toss	/vɒst - vɒts/
Test Items	/bleɪs - bleɪt/	/jeɪts - jeɪst/
	/dɪt - dɪt/	/dɪts - dɪst/
	/zest - zest/	/jeɪs - jeɪt/
	/bleɪst - bleɪts/	/pəʊts - pəʊts/
	/pəʊt - pəʊt/	/zet - zet/
	race - rate	messed - messed
	met - met	placed - plates
	goat - goat	miss - mitt
	rates - raced	plate - place
	goats - goats	mitts - missed

T2

Practice Items	/vɒs - vɒt/	/fest - fets/
	/tet - tet/	/vɒst - vɒts/
Test Items	/kets - kets/	hits - hissed
	/dɪts - dɪst/	messed - messed
	/pəʊts - pəʊts/	mitts - missed
	/zets - zets/	guessed - gets
	/fɒts - fɒst/	kissed - kissed
	/vɪts - vɪst/	rates - raced
	/jeɪts - jeɪst/	tots - tossed
	/bɪst - bɪst/	goats - goats
	/bleɪst - bleɪts/	placed - plates

Appendix 11
Experiment 4: Stimuli for ABX Task

T2 – List A

Word from which stimulus derived	A stimulus	B stimulus	X stimulus
Practice items			
	/səʊf/	/təʊf/	/səʊf/
	/spin/	/stin/	/stin/
	/ˈglɪzəs/	/ˈklɪzəs/	/ˈklɪzəs/
	/gɹɪb/	/sɪb/	/gɹɪb/
Test items			
Tractor	/ˈdɹektɪ/	/ˈtɹektɪ/	/ˈtɹektɪ/
Brush	/bɹɪs/	/bɹɪʃ/	/bɹɪʃ/
Spider	/ˈspeɪdɪ/	/ˈsteɪbɪ/	/ˈsteɪbɪ/
Glove	/gleb/	/glev/	/gleb/
Sponge	/spændʒ/	/spændz/	/spændz/
Jelly	/ˈdzʌlə/	/ˈdʒʌlə/	/ˈdzʌlə/
Flower	/ˈfluwɪ/	/ˈsluwɪ/	/ˈsluwɪ/
Train	/tɔɪn/	/tɹɔɪn/	/tɔɪn/
Caterpillar	/ˈkɪtəpælə/	/ˈkɪpətælə/	/ˈkɪpətælə/
Snake	/naɪk/	/snaɪk/	/naɪk/
Butterfly	/ˈbætəfləu/	/ˈbætəfəʊ/	/ˈbætəfləu/
Slipper	/ˈslɔpə/	/ˈlɔpə/	/ˈslɔpə/

T2 List B

Spaghetti	/spʌˈgɪtə/	/gʌsˈpɪtə/	/spʌˈgɪtə/
Pyjamas	/pɪˈdʒɔmɪz/	/pɪˈdʒɔbɪz/	/pɪˈdʒɔmɪz/
Aeroplane	/ˈɒɹəpɹəʊn/	/ˈɒɹəpləʊn/	/ˈɒɹəpɹəʊn/
Yellow	/ˈlæjɔɪ/	/ˈjælɔɪ/	/ˈlæjɔɪ/
Parachute	/ˈpeɹəsit/	/ˈpeɹəʃit/	/ˈpeɹəʃit/
Elephant	/ˈæfɪlɒnt/	/ˈælɪfɒnt/	/ˈæfɪlɒnt/
Guitar	/teˈgɔ/	/geˈtɔ/	/geˈtɔ/
Umbrella	/æmˈbɹælɪ/	/æmˈblæɹɪ/	/æmˈblæɹɪ/
Fish	/veʃ/	/feʃ/	/feʃ/
Plate	/pəʊt/	/pləʊt/	/pləʊt/
Van	/vɪn/	/zɪn/	/vɪn/
Sausage	/ˈsedʒəs/	/ˈsesədʒ/	/ˈsedʒəs/