The Relationship between Verbal Short-Term Memory and Language Processing Mechanisms

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Abstract

The central issue addressed in this thesis was how mechanisms and representational capacities existing for the processing of speech are involved in verbal short-term memory functioning. To this end, six experiments were conducted in which various language variables were manipulated, and the consequent effects on immediate verbal memory and speech input and output processing examined. In addition, direct links between performance on each word in the memory and language tasks were analysed. Word concreteness had significant effects on Immediate Serial Recall performance in four experiments, indicating an important role for semantic information in verbal memory. This variable also influenced performance in various speech processing tasks, with particularly consistent effects emerging in certain measures of speech production. In a further experiment, semantic ambiguity effects were observed in two measures of input processing, but not in immediate verbal memory. Finally, facilitatory word frequency and neighbourhood size effects were found in Immediate Serial Recall and in various measures of speech production. However, while frequency also benefited performance in two speech perception tasks, inhibitory effects of neighbourhood size were observed in these measures. These findings would suggest variable effects to emerge in verbal short-term memory primarily through the operation of mechanisms serving speech production. In line with this, regression analyses in each experiment revealed that the only measures to significantly predict each participant's recall of each item were Definition Naming and Speech Rate. Memory performance was not related to word recognition. These experiments support a model in which phonological and semantic short-term retention is dependent upon persisting activation within the speech processing system, with a particular reliance on mechanisms within the output pathway.

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Author's Declaration

I, Richard Allen, declare that the work presented in this thesis is my own, carried out between October 1999 and December 2002 at the University of York under the supervision of Professor Charles Hulme.

Chapter One

Models of Verbal Short-Term Memory and Language Processing

Short-term memory is vital for everyday functioning. Without the ability to temporarily retain and process information, and compare the results with what we already know from previous experience, all our words, thoughts, and actions would be meaningless and disconnected. We would become like Leonard Shelby in 'Memento', living through scribbled notes and forever asking 'Now.... Where was I?'.

The importance of short-term memory for wider abilities can be specifically applied to the temporary retention of verbal information. Verbal short-term memory has been linked to the operation of many other cognitive faculties (e.g. Atkinson & Shiffrin, 1971; Baddeley, 1986; Baddeley, Gathercole, & Papagno, 1998; Gathercole, Hitch, Service, & Martin, 1997;

Baddeley & Hitch, 1974; Gupta & MacWhinney, 1997; Hitch, 1978, 1980; Michas & Henry, 1994). These have included speech comprehension and production, vocabulary acquisition, reading, and mental arithmetic. Successful performance of such operations would be impossible without the ability to temporarily hold information in verbal form during processing. It is therefore apparent that verbal short-term memory contributes to a variety of cognitive processes. However, the nature of this relationship remains unclear. While short-term memory has often been described as a separable sub-system, it may be that other cognitive facilities themselves contribute to memory functioning. Specifically, as verbal short-term memory by definition involves the temporary storage of linguistic information, it is important to investigate connections with the wider language system. It may be that speech processing mechanisms directly contribute to how well we can temporarily hold speech-based information in mind.

This chapter will provide a brief historical context of short-term memory research. A detailed discussion and evaluation of work on temporary verbal memory, language processing, and the possible links between these cognitive abilities, will follow. The empirical work presented in the subsequent chapters will attempt to clarify how these systems may be connected, and will be addressed particularly toward the validity of a potential model.

1.1 Short-Term and Long-Term Memory: Unitary or Separable Systems?

An issue that is central to all verbal memory research concerns the extent to which there exists separable systems for the temporary and long-term storage of information, or whether all verbal storage occurs within a single memory system. This question is particularly relevant to the issues examined in this thesis. Any attempt to describe the possible relationship between short-term memory and speech processing would be heavily influenced by how temporary verbal storage relates to long-term language knowledge.

The conception of short-term memory as a temporary storage system, possibly separable from long-term processing, is often traced back to the work of William James (1890/1950). James discussed 'primary memory' and 'secondary memory', systems concerned with the 'psychological present' and the 'psychological past' respectively. Although this argument was couched more in terms of conscious awareness than short-term memory per se, it is still generally viewed as the precursor to modern-day research on temporary memory as a distinct system.

The forerunners of standard empirical paradigms used in modern research originated from a similar period, and they too appeared to suggest a multi-faceted memory process. Galton (1883) and Jacobs (1887) devised memory span tests, in which participants attempt to recall a series of items in their original order. Performance in these tasks appeared to differ quantitatively, and possibly qualitatively, from performance in measures of long-term storage.

Brown (1958), and Peterson and Peterson (1959) provided an empirical direction that held sway for some time, indicating a distinction between short-term and long-term memory. In the Brown-Peterson measure (recall of items following a distracting task), performance was poor even using small numbers of items. As a distracting task would not adversely affect the retrieval of information from long-term storage, these findings were interpreted as evidence for a distinct and fragile short-term store, from which information passively decays. However, subsequent investigations revealed the Brown-Peterson task to tap elements of long-term processing, on top of any temporary storage mechanisms (Baddeley 1990; Baddeley & Scott, 1971;

Keppel & Underwood, 1962; Loess 1968). Nevertheless, research using the Brown-Peterson paradigm appeared to provide support for a distinction between temporary and long-term storage.

An alternative view was held by Melton (1963), who proposed an influential unitary memory approach. He argued that many of the phenomena observed in short-term memory tasks could be accounted for with long-term mechanisms, and that performance on measures of temporary memory often show long-term memory influences. For example, the loss of information in the Brown-Peterson task could instead be explained through interference, a process that can cause information loss from long-term memory. Similarly, the Hebb effect (Hebb, 1961), in which participants perform better on lists they have previously heard, would appear to indicate a role for stored knowledge in short-term memory tasks. As these measures do not provide evidence for a separable temporary memory store, Melton instead suggested memory to be a unitary system in which information can be stored over a range of time periods.

Another approach that has often been cited as an influential unitary argument was the levels of processing theory (Craik & Lockhart, 1972). In what is essentially a framework to describe learning processes, they drew a distinction between items that receive shallow processing and those that are processed more deeply at initial encoding. Their argument was that shallow processing at encoding would result in comparatively poor later recall, whereas the deeper an item is processed (e.g. in terms of meaning, Craik & Tulving, 1975) the better retention will be. Postman (1975) and others have interpreted this account as a description of temporary and long-term memory operating within a single system, as shallow and deeper processing levels respectively.

However, subsequent work has undermined the use of the Craik and Lockhart theory as a general account of memory processing. Questions have been raised regarding both the reliability of processing level effects (e.g., Mechanic, 1964; Nelson, 1977) and the possible circularity involved in depth of processing research (Eysenck, 1978). Furthermore, Craik and Lockhart themselves drew a distinction between primary memory (where processing occurs) and long-term storage.

If the authors of what is often cited as a unitary memory theory make a claim for distinct temporary and long-term stores, this would appear to suggest that separable ST-LT models constitute a more plausible direction to follow. Indeed, the majority of subsequent theoretical work has adopted this approach, and a corpus of evidence has emerged in support of distinct short-term and long-term stores. For example, temporary coding has been shown to be phonological in nature (e.g. Conrad, 1964), whereas long-term coding is more meaning based (Baddeley, 1966). Furthermore, short-term storage has been shown to have a very limited capacity either in terms of item number or time (e.g. Baddeley, Thomson, & Buchanan, 1975; Miller, 1956). In contrast, few have attempted to place a limit on long-term capacity.

However, although such studies suggest variation in factors such as temporal and item capacity between short- and long-term memory, they do not provide conclusive evidence in support of separate stores. Indeed, the differences that have been observed merely serve as a reminder of why the debate occurred to begin with, and why verbal short-term memory remains the focus of much empirical interest. If participants' performance on short-term memory tasks revealed an unlimited capacity in terms of time and chunks of information, comparable to retrieval from LTM, the term 'short-term memory' would be redundant. The alternative, unitary approach still remains plausible, with short-term memory possibly reflecting an activated portion of stored language knowledge. The degree to which short-term and long-term representations form part of unitary or separable systems therefore remains unclear. It is hoped that some insight into this issue will be gained through a discussion of various models of short-term memory and language processing, and an examination of the central issue of how the ability to temporarily hold verbal information may relate to language processing.

1.2 Immediate Serial Recall

Before commencing a discussion of more recent models of verbal short-term memory, it is important to outline the main methodology with which this thesis is concerned. The ability to hold information for a short period of time has been measured using a wide variety of tasks, from matching span, to serial recognition, to free recall. Such tasks have been used in an attempt to tap various aspects of verbal short-term memory, such as encoding, storage, retrieval, and item or order retention. Although all measures have advantages and disadvantages depending on the area of verbal memory the experimenter is interested in, this thesis is particularly concerned with mechanisms underlying Immediate Serial Recall. In this task, a short sequence of items is presented either visually or aurally. Immediately after each presentation, the participant attempts to recall the list in its original order.

As the main focus of this discussion concerns the possible mechanisms underlying short-term memory as a whole, it was deemed necessary to examine a task that requires successful completion of all elements of short-term memory. For accurate Serial Recall performance, information must be initially perceived and encoded. Stable retention of both item and order information must then remain active, before each item is selected and produced as a response at output. Although a common tool in cognitive research, the mechanisms governing performance in Serial Recall remain unclear. A discussion of attempts that have been made in the last thirty years to explain temporary verbal memory processing, as measured by tasks such as ISR, will now proceed.

1.3. The Working Memory Model

Baddeley and Hitch (1974) proposed a highly influential theory that attempted to address the possible purposes of short-term memory, and in doing so produced a model central to arguments for an independent, specialised verbal store. This approach expanded on earlier work (e.g. Atkinson & Shiffrin, 1968; Hunter, 1964; Rumelhart, Lindsay, & Norman, 1972; Waugh, 1970) identifying the ability to temporarily hold information as being vital for wider cognitive functioning. The working memory model (illustrated in Figure 1.1) described the temporary storage and processing of verbal and visual information using three key components.

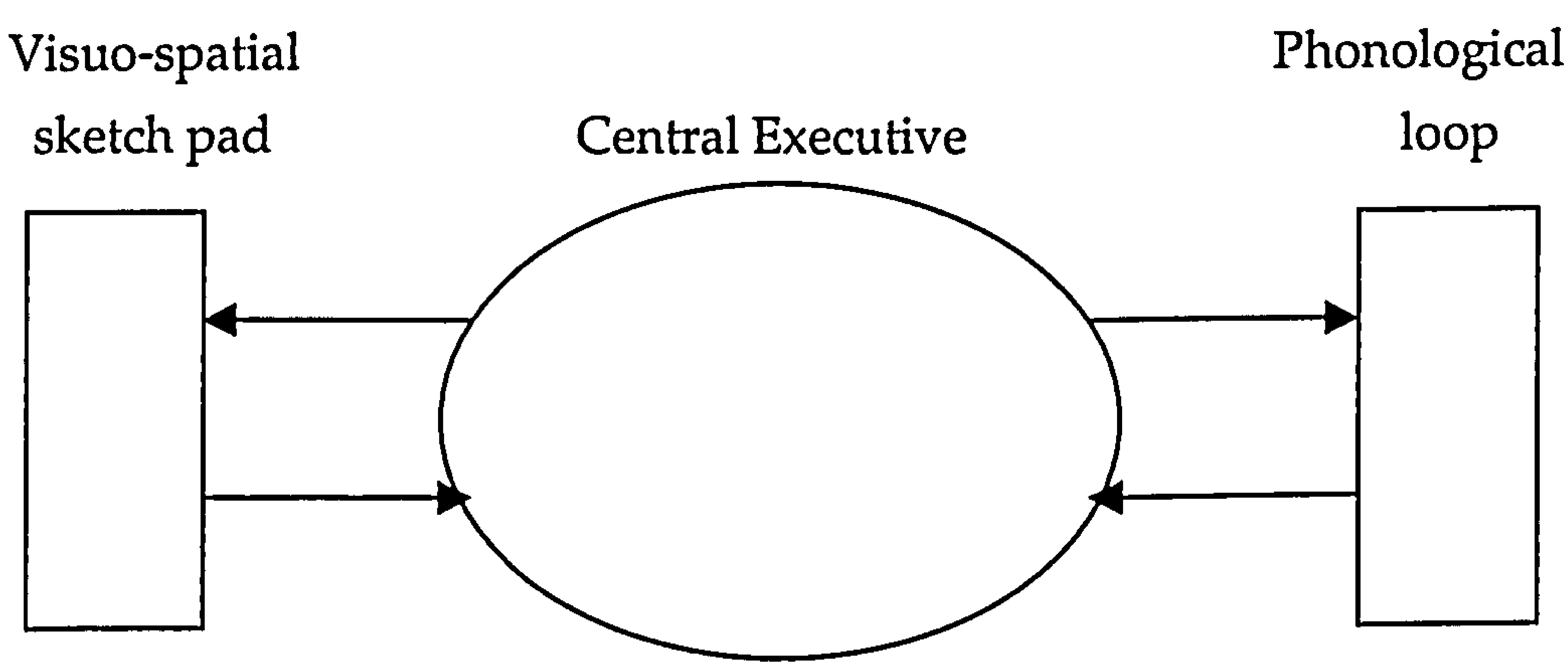


Figure 1.1. The Baddeley and Hitch (1974) working memory model. From Gathercole and Baddeley (1993)

Baddeley and Hitch identified the 'central executive' system as the most important component of working memory. A modality-independent system, the central executive controls information flow, retrieving information from other stores (e.g. LTM), and regulating the overall operation of working memory. In addition, it is thought to be capable of storing some information temporarily should a slave system (see below) be full or impaired.

While the central executive is primarily concerned with information processing and control, Baddeley and Hitch specified two slave systems, designed for information storage. The first of these was the 'visuo-spatial sketch pad', specialised for the short-term storage of visual and spatial information. The second slave system, and the most important and relevant for the present discussion, is the 'phonological loop' (originally termed the 'articulatory loop'), specialised for verbal information storage. This holds words in the form of a speech-based phonological code. Forgetting occurs primarily through temporal-based trace decay, with information decaying beyond recognition after around two seconds. However, information can be refreshed before it irretrievably decays through a process of subvocal rehearsal.

Baddeley (1986) later proposed a revised version of the phonological loop model, as illustrated in Figure 1.2. Although in essence very similar to the original conception, the new model described subvocal rehearsal as a separate process that acts to recode visually presented information into a speech-based phonological form, and refresh that information once it is stored within the loop. Although auditory information also requires rehearsal to limit decay, Baddeley claimed that its initial encoding into the loop occurs automatically, as it is already in phonological form. Thus, the working memory model made explicit connections between temporary verbal memory and speech processing, while retaining the key notion of STM as an independent, specialised sub-system.

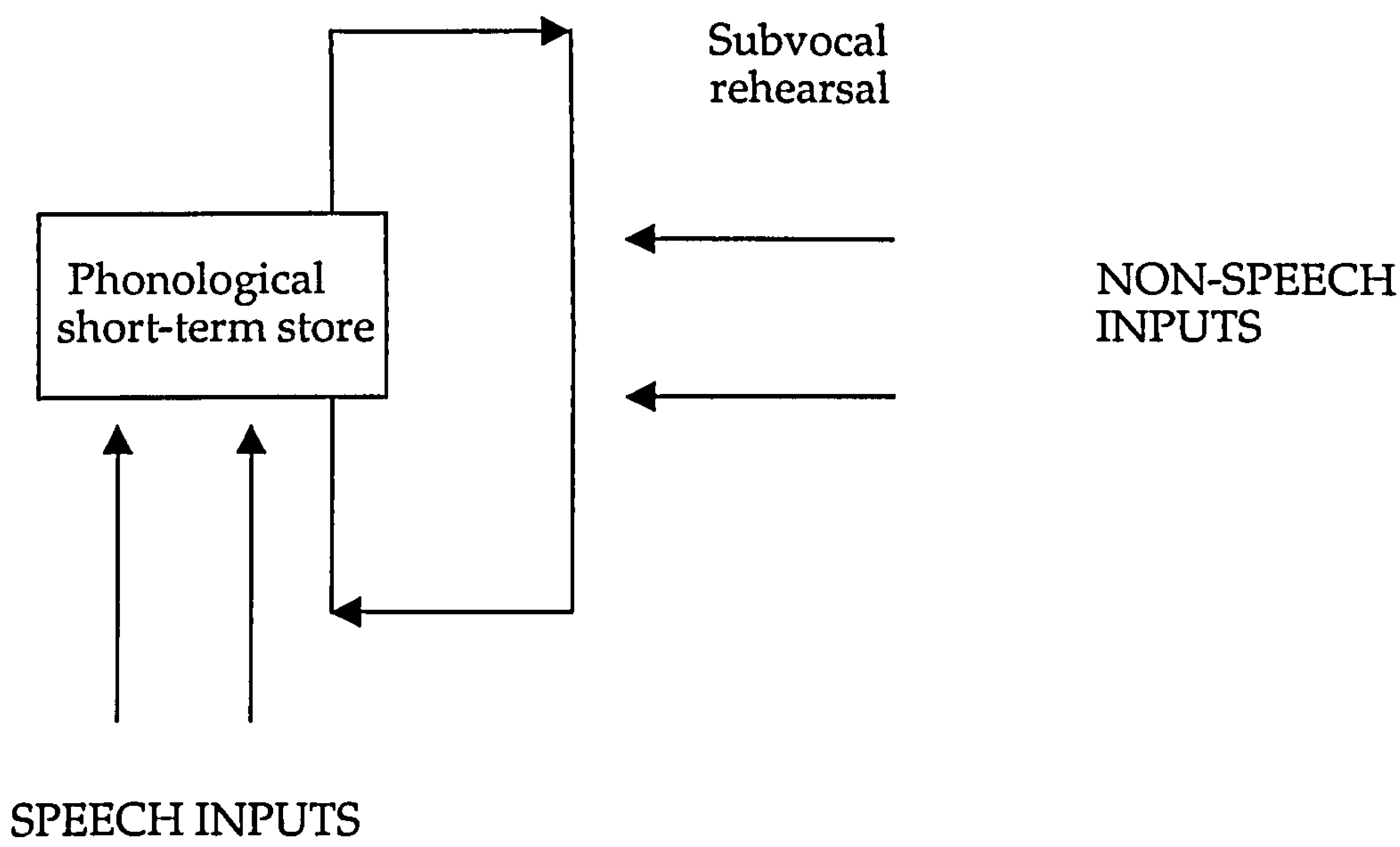


Figure 1.2. The revised phonological loop model.
From Gathercole and Baddeley (1993)

1.3.1 Evidence for the Phonological Loop Model

The phonological loop model (Baddeley, 1986; Baddeley & Hitch, 1974) was devised primarily to account for four central strands of evidence relating to temporary verbal memory performance.

The first of these was the effect of articulatory suppression, whereby participants simultaneously perform a short-term memory task whilst overtly articulating irrelevant material. This procedure has been shown to severely hinder recall performance (e.g. Baddeley et al., 1975, 1984; Estes, 1973; Levy, 1971). As suppression occupies the speech processing system, rehearsal cannot operate to refresh decaying traces (Baddeley, 1986). Performance on visually presented lists is particularly impaired by articulatory suppression, as the translation of information into a phonemic code is prevented under this condition.

A second form of evidence crucial to the development of the idea of phonological loop theory is the word length effect. Baddeley, et al. (1975) observed a linear relationship between memory span and articulation rate, with performance better not only for shorter words, but also for words with shorter spoken durations (controlling for syllables and phonemes). These findings have been interpreted as support for the notion of immediate verbal memory as a temporally limited, speech-based store, with a capacity governed by the rate at which materials can be articulated (and thus refreshed) before they decay. In line with this argument, the word length effect is abolished under articulatory suppression, as this prevents participants from effectively rehearsing the items (Baddeley, et al, 1975, 1984). Estimates of the phonological loop's temporal capacity have been consistent, at approximately 1.8-2 seconds (Baddeley & Hitch, 1974; Baddeley et al., 1975). Thus, memory would be limited to the amount of information that can be rehearsed in that time.

Hulme, Thomson, Muir, and Lawrence (1984) took a developmental perspective to the articulation rate-memory span relationship. They examined the performance of children across a range of ages, and observed a linear recall-speech rate function in all age groups. In line with the phonological loop model, Hulme et al. suggested age-related memory improvements (e.g. Chi, 1976) to be attributable to increases in articulation rate, rather than any actual enlargement in temporal capacity.

The phonological similarity effect is also interpreted as evidence for a speech-based memory system. Memory span is often reduced on lists of similar sounding items (Baddeley, 1966a; Conrad, 1964; Salame & Baddeley, 1982). Furthermore, this effect contrasts with the word length effect, in that it is only abolished under suppression when list presentation is visual (as opposed to auditory). Baddeley (1986) argued that the similarity effect normally arises due to confusion between decaying speech-based traces.

Items presented in the auditory modality automatically enter the phonological loop, and so similarity effects will emerge even under suppression. In contrast, as suppression prevents the phonemic recoding of visual stimuli, items will not be stored in the phonological loop system, and so phonological similarity becomes irrelevant to performance.

A final source of support for the phonological loop approach has been derived from unattended speech effects. Salame and Baddeley (1982) observed that hearing speech sounds during a memory span task impaired performance, particularly when those sounds were phonologically similar to the test stimuli. It was claimed that the irrelevant speech automatically enters the phonological loop and disrupts processing of list items, thus reflecting the speech-based nature of temporary verbal storage.

1.3.2 Problems with the Phonological Loop Model

The working memory model in general, and the phonological loop theory in particular, heralded important changes in short-term memory research. They suggested potential connections between verbal STM and other cognitive processes that are still being examined. Importantly for the present discussion, the phonological loop model explicitly linked verbal memory with speech processing. Temporary storage and the processes that operate on it (i.e. rehearsal) were seen as essentially speech-based, time-limited mechanisms. However, the model leaves a number of critical questions unanswered. For example, although verbal information is described as being temporarily held in a phonological or speech-based form, the basis of this storage remains unclear. How is this information held, and on what functional basis does sub-vocal rehearsal operate?

In addition, questions have been raised concerning the model's ability to account for short-term memory phenomena. For example, it fails to explain how order information is coded in temporary verbal memory (Burgess & Hitch, 1992). Similarly, although it describes the language-based form of information coding, it is not specified precisely where this storage occurs and how it relates to other speech mechanisms (e.g. input and output processing). This is a question central to the present discussion.

More recent research has emerged to suggest a re-evaluation of original phonological loop evidence. For example, Jones et al. (Jones, 1990, 1993, 1994; Jones, Beaman, & Macken, 1996; Jones & Macken, 1993; Jones, Madden, & Miles, 1993) have argued that the irrelevant speech effect is in fact due to the changing state of irrelevant sounds, rather than any interfering influence of the speech. Jones et al. suggest that any changing sound can disrupt short-term memory performance, through interference with the seriation of list items. Baddeley's claim that irrelevant speech effects reflect the speech-based nature of the store (Baddeley, 1986; Salame & Baddeley, 1982) was refuted as Jones and Macken (1993) observed similar disturbance with non-speech sounds.

Similarly, the notion that articulatory suppression prevents a visual to phonemic code translation (Baddeley, 1986) is questioned by recent evidence. Fallon, Groves, and Tehan (1999) observed phonological similarity effects using visually presented lists under suppression. The phonological loop model would predict such effects to be abolished. Furthermore, Fallon et al.'s finding that similarity actually improves item recall (but impairs list position accuracy) suggests processes not previously discussed by the model.

Word length effects have also been reinterpreted. For example, Longoni, Richardson, and Aiello (1993) questioned the necessity of rehearsal processing, the mechanism identified by Baddeley (1986) as being responsible for such effects. Similarly, Brown and Hulme (1995) produced a simple decay-based computational model, which attributed word length effects to output interference at recall. It was demonstrated that retrieval and articulation of items leads to degradation of the traces of subsequent items. As long words take longer to say, output interference will be more severe. Support for this view was produced by Cowan, Saults, Keller, Johnson, & Flores (1992), who found that, with longer items positioned early in immediate serial recall lists, interference was greater for subsequent items positioned towards the end of the lists.

Alternatively, word length effects have been explained in terms of phonological complexity (e.g. Service, 1998). Caplan, Rochon, and Waters (1992) equated items of different lengths on their complexity and abolished the effects of word length. Similarly, Walker and Hulme (1999) observed word length effects in a matching span task requiring no verbal output. They claim that the word length effect as observed in serial recall tasks may reflect both output processes and phonological complexity, with long complex words placing greater demands on encoding and storage of phonological information, and causing more interference at response production.

It is therefore evident that the phonological loop approach is inadequate in its explanation of a range of short-term memory phenomena. Many researchers have suggested alternative roles for rehearsal. Cowan et al. (Cowan, Wood, Wood, Keller, Nugent, & Keller, 1998) argued for separable roles of retrieval processing and rehearsal strategies in temporary verbal memory. Brown, Vousden, McCormack, and Hulme (1999) suggested that rehearsal serves to increase the temporal distinctiveness of traces in short-term memory. Although the role of rehearsal may have been overestimated in importance by phonological loop accounts, it could still be influential in immediate memory processing. However, rather than representing an integral function in the underlying basis of memory processing, rehearsal may be viewed as a conscious mnemonic strategy, useful in improving short-term memory performance.

Although considerable evidence has been obtained to suggest the phonological loop model is an oversimplification, researchers have sought to reinterpret and extend the theory rather than reject it. Its central claims regarding the speech-based, temporal capacity of the verbal store remain plausible. Indeed, recent evidence has emerged indicating a yet more integral role for speech and language processing mechanisms in verbal short-term memory.

1.4 The Influence of Stored Language Knowledge

The model described by Baddeley (Baddeley & Hitch, 1974; Baddeley, 1986) succeeds in providing explanations for many phenomena that have been observed in studies of short-term memory. However, subsequent research has questioned both the ability of this approach to account for many findings, and the strength of its supporting evidence. Furthermore, the focus of this model was limited for the most part to the temporary storage of phonological information, and the influence of auditory and articulatory factors. A number of recent studies have suggested that stored language knowledge and multiple linguistic coding have an influential role in temporary storage and retrieval.

1.4.1 Lexicality

Hulme, Maughan, and Brown (1991) found an advantage in recall for words that were shorter and could be articulated at a faster rate, thus supporting the claim that verbal short-term memory contains a speech-based, time-limited component reflecting speed of rehearsal. However, Hulme et al. also observed that memory span was lower for nonwords than words, a finding independent of speech rate and word length differences. This finding was taken to reflect the absence of stored representations of the phonological forms of nonwords in long-term memory, and has since been replicated (e.g. Gathercole, Pickering, Hall, & Peaker, 2001). Thus, lexicality effects may reflect the influence of language processing mechanisms on the temporary storage of verbal information. Phonological loop theory cannot account for such findings, as it would predict that only variables differing in actual phonological or articulatory features would affect performance.

1.4.2 Wordlikeness

Not only has variation in performance been observed between words and nonwords, it has also been found within nonwords. When attempting to recall lists composed of nonwords, participants tend to perform better on items that are phonologically similar to real words. For example, children have been shown to be more accurate in non-word repetition tasks (assumed to be a measure of phonological STM) on nonwords that are high in their degree of rated wordlikeness (Gathercole, 1995; Gathercole, Willis, Emslie, & Baddeley, 1991). A similar pattern of results has also been observed in standard recall tasks (Gathercole, Frankish, Pickering, & Peaker, (1999).

1.4.3 Word Frequency

If lexical status can influence short-term memory, it would be predicted that any other factor varying in how items are represented long-term would affect performance. In an early experiment, Watkins (1977) found a memory span improvement when words presented early in a list were of higher frequency than those that were presented later. This was attributed to the influence of LTM on recall of early items, with words at the end of lists being recalled directly from STM. However, this finding may reflect output interference, as Wright (1979) observed that low-frequency words take longer to articulate, thus causing greater degradation to subsequent items.

Nevertheless, Watkins' (1977) attribution of frequency effects to LTM mechanisms was a precursor to more recent research. Tehan and Humphreys (1988) and Gregg, Freedman, and Smith (1989) both found that memory span advantages for high-frequency over low-frequency words remained under articulatory suppression. Similarly, Hulme et al. (Hulme, Roodenrys, Schweickert, Brown, Martin, & Stuart, 1997; Roodenrys, Hulme, Alban, Ellis, & Brown, 1994) also uncovered beneficial word frequency effects on standard span tasks (but not backward recall) that were independent of speech rate differences.

1.4.4 Phonological Neighbourhood Size and Frequency

Words from large phonological neighbourhoods have many similar sounding neighbours, differing by as little as a single phoneme, while neighbourhood frequency refers to the average frequency with which these neighbouring words occur in normal language. Roodenrys, Hulme, Lethbridge, Hinton, and Nimmo (in press) examined the effects of word frequency, neighbourhood size, and neighbourhood frequency on performance in a series of memory span and Serial Recall tasks. They replicated the word frequency advantage noted previously (e.g. Hulme et al, 1997), and also observed significant beneficial effects of both neighbourhood size and frequency.

In a further experiment, Roodenrys et al. examined the effects of word frequency, neighbourhood size, and neighbourhood frequency on Serial Recall, conducting regression analyses to identify predictors of correct and erroneous responses. They found that word frequency and neighbourhood size accounted for significant variance in the production of correct responses, while all three variables predicted various forms of item errors. Specifically, they observed that words with more neighbours elicit both a greater number of correct responses, and a greater number of intrusions from phonological neighbours.

1.4.5 A Semantic Contribution to Verbal Short-Term Memory

The majority of verbal short-term memory research has focused on the ability to encode, maintain, and retrieve temporary phonological representations of words. On the basis of large phonological similarity effects, Baddeley (1966a) concluded that immediate memory depends primarily on phonological processing. However, Baddeley also observed a small but significant detrimental semantic similarity effect, thus suggesting semantic information to have a role in temporary verbal storage. Evidence of semantic similarity effects in short-term memory tasks have been contradictory however, with several other studies observing no effect (e.g. van der Lely & Howard, 1993), or facilitatory effects (e.g. Huttenlocher & Newcombe, 1976; Poirier & Saint-Aubin, 1995; Wetherick, 1975).

One possible source of such mixed results may be that articulatory speed was not controlled in many of the studies examining semantic similarity (Brooks & Watkins, 1990). Poirier and Saint-Aubin (1995) observed beneficial semantic similarity effects on recall even when an articulatory suppression condition was introduced (thus preventing subvocal articulation and avoiding speech rate confounds). They interpreted such findings as reflecting the influence of semantic long-term memory factors on short-term memory processing. However, this hypothesis still infers that temporary item information is primarily coded phonologically, with semantic effects emerging at a more general list level.

Evidence does exist for the involvement of semantic effects at the level of individual item processing. Tehan and Humphreys (1988) found a recall advantage for content words over function words, even after articulatory suppression. Bourassa and Besner (1994) abolished this word–class effect when they controlled for imageability, inferring that words of high imageability are easier to recall in STM tasks. One explanation of such effects on Serial Recall performance would be derived from the dual-coding theory of Paivio (1986). In this approach, words that are not imageable can only be stored using a verbal code, whereas imageable words are coded visually as well as verbally, thus providing greater support for processing. Although this may account for some variation in performance, the present review is concerned with temporary verbal memory. Recent research has discussed semantic effects in terms of this form of information.

1.4.5.1 Concreteness

Walker and Hulme (1999) examined the influence of semantic knowledge on verbal memory recall with the manipulation of rated concreteness. They refer to concreteness as "an index of how directly the referent of a word can be experienced by the senses" (p.3). Two initial experiments using spoken and written recall both found significant and independent effects of word length and concreteness. In a further experiment, Walker and Hulme examined such effects in a backward serial recall paradigm, which Hulme et al. (1997) found abolished frequency effects. A significant concreteness effect was still observed, suggesting frequency and concreteness effects to be mediated by somewhat different mechanisms. In a final experiment, this formally robust concreteness effect was abolished in a matching span paradigm, which involves no linguistic output, and so minimises demands on retrieval processes. On the basis of these findings, Walker and Hulme (1999) suggested verbal information to be temporarily coded in terms of semantics as well as phonology, and that this aids performance primarily at item recall.

1.5 Recent Models of Verbal-Short-Term Memory

As it became clear that the original phonological loop model was not able to account for emerging empirical findings, a series of new conceptions were put forward, often including elements of the phonological loop themselves. For models of immediate verbal memory to be successful, they must account not only for original phonological loop evidence, but also for these recent findings suggesting a role for phonological and semantic long-term memory and language processing in temporary memory. A selection of these theories will now be discussed.

1.5.1 The Phonological Loop and Long-Term Memory

In light of recent evidence, Baddeley et al. (1998) attempted a re-conceptualisation of the phonological loop and its functional purpose. They claimed that the loop's contribution to memory tasks is a by-product of its original and central purpose, that is, the facilitation of novel word acquisition. The argument they proposed is that short-term memory enables the initial storage and repetition of novel phonological forms, before and during their assimilation into long-term memory. Evidence can be drawn from the predictive relationship between nonword repetition and vocabulary knowledge in children (e.g. Gathercole, Willis, Emslie, & Baddeley, 1992). Furthermore, it has been found that new word learning is influenced by phonological loop phenomena such as articulatory suppression (Papagno, Valentine, & Baddeley, 1991), phonological similarity, and word length (Papagno & Vallar, 1992).

Importantly, Baddeley et al. (1998) proposed an interactive relationship between the phonological loop and long-term knowledge. They describe a language system in which '...the phonological loop is available to support the construction of more permanent representations of the phonological structure of new words, (and) established knowledge of the language is used to offset this fragile temporary storage component whenever possible.' (p. 170). This represents an extension of the phonological loop theory (Baddeley, 1986; Baddeley & Hitch, 1974) to accommodate the possible effects of wider language processing and long-term memory. However, Baddeley et al. still say little over and above the original theory concerning the nature of short-term storage. In addition, their extension retains the phonological focus of previous work, and thus does not allow for other forms of linguistic coding.

1.5.2 The Burgess and Hitch Model

The basic tenets of the localist connectionist network model proposed by Burgess and Hitch (1992, 1999) can be seen in Figure 1.3. This approach to temporary memory describes separate levels of nodes representing items, input phonemes, output phonemes, and a context-timing signal. As the model is localist, one node is taken to represent one phoneme or item.

At presentation, input phonemes are activated, which in turn activate a layer of item representation units and output phoneme units. Burgess and Hitch claim that the item representation most highly activated by input phonemes is associated with a temporal 'sliding window' context-timing signal, the output of a possible central timing system composed of similar temporal oscillators (as described by Treisman, Cook, Naish, and Crone, 1994).

At recall, the context signal is reset and the 'window' advances along the temporal sequence, thus cueing item retrieval. In addition, input node activation is fed forward to these word level nodes. As item representations have overlapping context signals and connected phoneme nodes, winner-takes-all competition will occur to determine which of the items activated by the context signal will be produced. A competitive queuing (Houghton, 1990) aids the representation of order and the selection process at response production. In this process, the most active item node is selected, then immediately suppressed, enabling subsequent selection of the item with the second highest activation level (which should be the next list item). Following each item selection, the relevant output phoneme nodes are activated and the response can be produced.

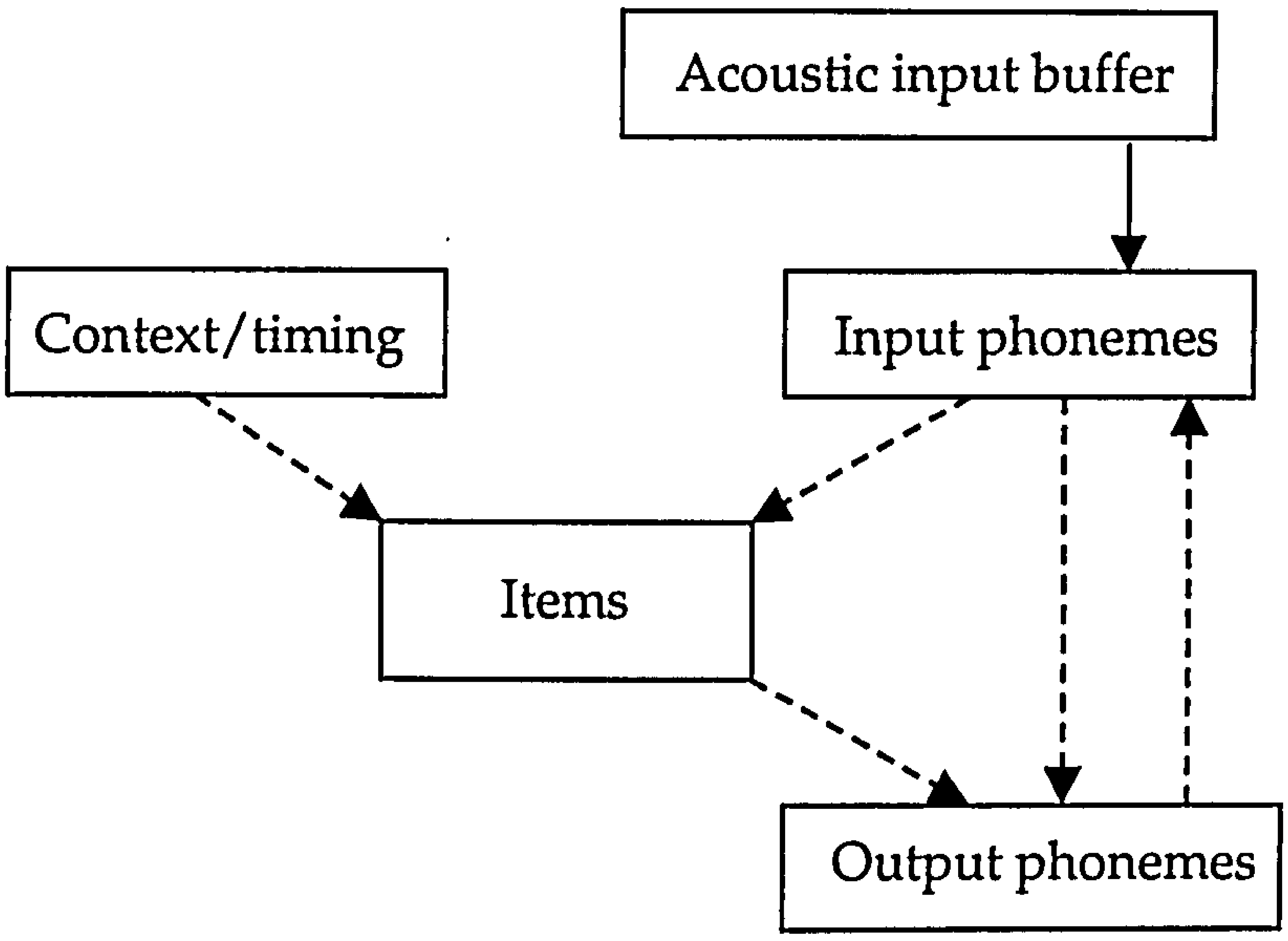


Figure 1.3. The Burgess and Hitch (1999) model of STM

In this model, item representations are modelled at a lexical level. Burgess and Hitch place the phonological short-term store at the layer of input phoneme nodes, with output phoneme nodes involved in rehearsal, output selection and competitive queuing, and response production. Forgetting occurs through the temporal decay of input phoneme and context signal activation levels. Rehearsal is modelled as an excitatory feedback circuit, from output phonemes to input phonemes, to item representations, and back to output phonemes.

In simulations, the model exhibited many short-term memory phenomena. Word length, articulatory suppression, and phonemic similarity effects were observed, as was the correlation between memory span and speech rate. The model also produced a pattern of errors equivalent to those observed in normal performance. The Burgess and Hitch model has therefore been shown to be a good match for item and order processing in short-term memory tasks, as it produced these effects as emergent properties of the model's architecture. Effects of variables such as frequency and lexicality could also be explained, as connections between item and phoneme nodes would be stronger for frequent and familiar stimuli. It also allows the accurate simulation of neuropsychological impairments, through a selective lesioning of connections. Furthermore, it is particularly relevant to the present discussion in that it specifies roles for both input and output phoneme processing in temporary verbal storage.

However, several shortcomings of the Burgess and Hitch (1992, 1999) model have emerged. As with many such theories, it remains a purely phonological approach to short-term memory. No consideration is made of other forms of coding, such as semantics, so no explanation is provided for concreteness effects in immediate verbal memory. In addition, the model does not accurately model the forming of new representations in long-term memory. The storage and processing of within-word phoneme order is not addressed, and Burgess and Hitch (1999) observe that the primacy effects in their serial position curves are very weak. Similarly, problems have emerged with the rehearsal mechanism in the model (Gupta & MacWhinney, 1997). Nevertheless, the Burgess and Hitch (1992, 1999) model has had a lasting influence on subsequent work.

1.5.3 The Gupta and MacWhinney Model

The influence of the earlier incarnation of the Burgess and Hitch model can be seen in the theory proposed by Gupta and MacWhinney (1997). This approach proposed a system based upon the Burgess and Hitch (1992) model for Serial Recall of words and the Houghton and Hartley (1996) nonword repetition model, itself partially based on the work of Burgess and

Hitch (1992). In combining these earlier models, and relating short-term memory to language processing, Gupta and MacWhinney (1997) attempted to bring together verbal short-term memory and vocabulary development research.

In this model, each item is represented as a node in the 'phonological chunk' layer, with the constituent phonemes held in a phoneme layer. As list items are presented, a phonological store automatically encodes varying vectors of chunk layer activation. The chunk nodes are linked directly to the phoneme layer and to a syllable template, and also to semantic representations. As an item is repeatedly presented, these connections strengthen and develop through Hebbian learning.

The proposed relationship between short-term memory and vocabulary development differed from that described by Baddeley et al., (1998; Gathercole & Baddeley, 1993), who suggested a causal link. Instead, Gupta and MacWhinney described a system wherein vocabulary acquisition and short-term memory have a shared basis in the same cognitive language system. They saw these abilities as having a common dependence on central phonological processes, and utilising mechanisms such as rehearsal and chunking. In particular, Gupta and MacWhinney discussed evidence indicating a shared basis for vocabulary development and short-term memory in the neural areas responsible for speech processing. They claim that '..the processes of immediate serial recall are firmly embedded within the overall speech processing system.' (p.269). It is suggested that phonological information may be temporarily held within a system specialised for input phonology, with output phonology mainly responsible for operating on, manipulating, and rehearsing this stored information.

This model is effective in that it accounts for many short-term memory phenomena, and it has a strong computational and empirical grounding in the previous models on which it is based. It also provides an explanation of how phonemes are sequenced within words, something its predecessors did not achieve. Importantly, the Gupta and MacWhinney model allows for the involvement of word meaning in short-term memory, and describes and interaction between semantic and phonological representations (as demonstrated empirically by concreteness effects). It also describes how words and nonwords are stored, and why the lexicality effect emerges. Under this approach, words and nonwords are qualitatively equivalent, but the former have stronger connections between the chunk node and other layers. This connection strength explanation can also be applied to frequency effects.

However, Roodenrys et al. (in press) argued that the Gupta and MacWhinney model would predict inhibitory neighbourhood size effects in recall, through the process whereby the phonological store re-actives the chunk layer of the vector at recall. As similar words produce similar activation patterns in the chunk layer, and similar vectors in the phonological store, the more neighbours a word has, the greater the likelihood would be of the phonological store activating the incorrect chunk, and consequently recalling one of those neighbours. This is in direct contrast with the findings of Roodenrys et al.

1.5.4 The Feature Model

This model was designed to account for the major effects observed in Immediate Serial Recall (Nairne, 1988, 1990; Neath & Nairne, 1995). It describes primary memory (a real-time record of temporal order information) and secondary memory (the permanent store of information, analogous to long-term memory). Information is maintained and constructed in these stores in the form of vectors of features. Primary vectors of features are subject to interference-based degradation, which is said to influence many aspects of short-term memory, including encoding, rehearsal, and recall. At recall, the remaining features contained in partially degraded primary memory traces are used as cues to establish, via a best relative match process, which of the items represented in the secondary memory search set were part of the presented list. This search set is assumed to be limited to recently presented items. If a primary trace has lost some of its features, the probability of accurate matching will be reduced.

The feature model identified a distinction between modality-dependent and modality-independent features of words. For example, features may vary according to the stimulus presentation event (modality-dependent), or according to the actual items presented (modality-independent). Abstract forms of representation, such as a word's semantic, orthographic, or phonological make-up would constitute modality-independent features.

This model is able to explain a number of short-term memory phenomena, such as suffix effects, modality effects, recency effects, and the limited capacity of STM. It uses a simple system to account for many such findings, and also allows for separate encoding of order and item information, something the phonological loop model does not attempt. The feature model could also be easily extended to provide an account of the effects of lexicality and frequency (e.g. Hulme et al., 1991, 1997). Furthermore, it could be used to describe the involvement of multiple linguistic codes in STM, with features possibly representing meaning as well as phonology and orthography (Walker & Hulme, 1999). For example, as concrete words would have more meaning-based features associated with them (Plaut & Shallice, 1993), they will be matched more easily to secondary memory representations.

However, the model does not provide an adequate explanation of neighbourhood effects in Immediate Serial Recall (Roodenrys et al., in press). The restriction of the secondary memory search set to recently presented information means that phonological neighbours would not influence memory performance. In addition, a shortcoming of the approach is that it describes short-term feature coding, separable from long-term memory, without specifying how this information is temporarily represented.

1.5.5 Redintegration

1.5.5.1 Phonological Coding and Redintegration

Following work by Hulme et al., (1991) and others (e.g. Hulme et al., 1997; Schweickert, 1993), Hulme, Newton, Cowan, Stuart, and Brown (1999) proposed a multi-component model of verbal memory retrieval, in which items are stored as a phonological code. This coding involves information regarding the identity of items and the order in which they occurred. In order for items to be successfully recalled, participants must access these phonological codes at output. However, difficulties arise in that these representations are participant to degradation, arising in part from output interference (Cowan, 1992; Cowan et al., 1994; Hulme et al., 1997).

The Hulme et al. (1999) model is primarily concerned with retrieval mechanisms. They specify this to involve at least two stages, and to occur automatically in the pauses between recall of each item. Firstly, it is proposed that items are retrieved from the temporary phonological store via a process of memory search and trace selection. Although not necessarily a serial process as Sternberg (1966) claimed, it has been argued that the majority, if not all, of the list is searched before the retrieval of each item (Cowan et al., 1998).

This theoretical direction has developed in part from a series of experiments by Cowan and colleagues on fine-grained analyses of response times recorded in standard short-term memory tasks. They observed that the duration of pauses between the recall of each item had a negative correlation with memory span and age, but were not connected to word length, spoken response duration or rapid articulation (Cowan, 1992; Cowan et al., 1994, 1998). However, Cowan et al. (1998) did find a significant correlation between memory search (using the Sternberg, 1966, probe task) and span. These findings led them to conclude that temporary item representations are searched for and 'reactivated' during the pauses between participants' responses. Such retrieval-based memory processes are thought to develop through childhood, and are independent of the effects of other processing rates, such as rehearsal or stored language representations.

The second component of Hulme et al.'s retrieval model is termed 'redintegration'. It is claimed that, once a temporary phonological trace has been selected, it can be successfully produced in one of two ways, as discussed by the multinomial processing tree (Schweickert, 1993). If the trace is complete, it is simply retrieved and articulated. However, if it is partially degraded, it must be restored before output can occur. Remaining phonological information in the temporary trace is matched to phonological representations of words in long-term memory. These then aid an automatic restoration or 'redintegration' process on degraded traces, defined in computational terms as 'the clean-up of noisy representations' (Brown, 1990; Hulme et al., 1991; Schweickert, 1993).

Hulme et al. (1991, 1997, 1999) suggested that this redintegration process is analogous to processes operating in speech perception, and may be based on mechanisms existing primarily for speech processing. They asserted that the effects of redintegration in verbal memory tasks may be 'a by-product of mechanisms that exist for the perception and production of speech' (Hulme et al., 1997, p. 1220).

The model predicts that the likelihood of an item being retrieved depends on whether participants possess a well-defined stored phonological representation in long-term memory. As nonwords do not have well-defined stored representations of their phonological forms, redintegration will be inefficient and inaccurate, meaning only the temporary traces of nonwords that have not significantly decayed will be successfully recalled (Hulme et al., 1991).

Subsequent research has supported this approach. Schweickert, Chen, and Poirier (1999) argued that the lexicality effect selectively influences redintegrative processing in verbal STM tasks. Gathercole et al. (2001) also placed the origin of the word-nonword advantage at redintegration. They failed to observe such effects in serial recognition, a task not thought to involve the need for significant restorative processes, as target items are presented again at the response stage. Similarly, Hulme, Roodenrys, Brown, and Mercer (1995) observed improved recall of nonwords after simple phonological training on these items, reflecting the use of newly created representations in the pattern completion of degraded traces. In addition, in their computational model, Brown and Hulme (1995) successfully simulated the lexicality effect in verbal short-term memory with a redintegration process.

Redintegration theory has also been applied to frequency effects. Hulme et al. (1997) concluded that high frequency words provide more effective support at retrieval for redintegration, as their representations in LTM are either more accessible or better specified, relative to those of low-frequency words (Mandler, 1980; Scarborough, Cortese, & Scarborough, 1977). Therefore, the stored representations of high frequency words would be more likely to be successfully matched with degraded temporary information, and would provide more support for restoration.

Without a role for stored language knowledge, frequency and lexicality effects would not emerge in verbal memory tasks. In contrast, it is likely that other variables such as word length and phonological similarity would affect short-term memory performance, regardless of any involvement of stored representations or wider language processing. For this reason they have been interpreted as evidence for an independent phonological loop system. However, redintegration has recently been identified as a possible source of phonological similarity effects in Serial Recall, through problems with trace matching following degradation of phonological coding (Gathercole et al., 2001; Saint-Aubin & Poirier, 1999; Schweickert et al., 1999). In addition, word length may influence this process, with redintegration proceeding more effectively and usefully for long than short words. The partial loss of phonological information from the traces of long words would have less serious consequences for retrieval than decay of shorter words, as a greater cue would remain after degradation (Brown & Hulme, 1995; Hulme et al., 1997; Schweickert, Hayt, Hersberger, & Guentert, 1996).

1.5.5.2 Semantic Coding and Redintegration

Walker and Hulme (1999) discussed how the redintegration theory could be extended to take in semantic coding. They argued that items are also coded semantically in short-term memory, and that at retrieval, these temporary semantic traces are compared with and restored on the basis of representations in semantic long-term memory. The roles of phonological and semantic coding in short-term memory are seen as being distinct and separable, due to the differential effects of concreteness and frequency on backward recall performance.

A word's meaning may be represented in long-term memory either as a structured set of semantic features in a localist network (e.g. Collins & Loftus, 1975), or as part of a distributed semantic network (e.g. Gaskell & Marslen-Wilson, 1997). Under either approach, redintegration would be more efficient for concrete words, as they are thought to have richer semantic representations than abstract words (e.g. Plaut & Shallice, 1993), with a greater number of associated features. Thus, the degraded semantic traces of concrete words will be easier to match with, and receive greater activation from, the corresponding representations in semantic long-term memory.

The redintegration model provides an explanation for the recent findings indicating a role for long-term language representations in temporary memory (e.g. lexicality, frequency, and concreteness). It has also been applied with some success to other short-term memory phenomena, such as phonological similarity and word length, as well as recency effects and error patterns across serial positions (Lewandowsky, 1999). It provides a relatively simple account of the possible processes operating at word retrieval, with this focus allowing a possible integration with other, more general models of memory processing.

1.5.5.3 Shortcomings of the Redintegration Account

Due to this limited remit however, redintegration theory cannot independently provide a detailed description of precisely how item and order information are represented. The description of a system wherein temporary traces are compared to long-term representations means that an autonomous phonological store, similar to that described by Baddeley (1986), may necessarily be the model's basis of short-term item representation. However, this approach is ill defined regarding the nature and basis of temporary storage.

Recent work by Stuart and Hulme (2000) has questioned redintegration as being the underlying cause of the advantage for high-frequency words. It has been found that the frequency effect is eliminated in mixed lists of high- and low-frequency words, suggesting that it is not located purely at the item level (May, Cuddy, & Norton, 1979; DeLosh & McDaniel, 1996). Deese (1959, 1960) instead proposed that frequency effects in free recall arise from the frequency of word co-occurrence, rather than the frequency of the words themselves. Stuart and Hulme tested this by improving associative links between words through repeated pre-exposure of item pairs, followed by Serial Recall. They observed that this procedure improved recall of low frequency words to the level of high frequency performance, suggesting the original effect not to be the result of an individual item-level redintegration advantage. Nevertheless, Stuart and Hulme attempted to reconcile these findings with redintegration theory, arguing that inter-item associations enable the creation of a mutually supportive network of item nodes in long-term memory. This network would make item representations more accessible, and support temporary trace reconstruction.

The redintegration approach would predict inhibitory neighbourhood effects in Serial Recall, as the degraded phonological trace of a word from a large neighbourhood would be more likely to be matched with and restored on the basis of an incorrect neighbour. While the error analysis reported by Roodenrys et al. (in press) provided some evidence for this process, the overall beneficial effect was in direct contrast to this prediction.

Walker and Hulme (1999) propose that concreteness effects do not emerge during temporary storage, but at the point of pattern matching with long-term representations. However, as stored semantic representations must first be accessed to create temporary semantic coding, it is plausible that concrete words are more efficiently and strongly encoded, and consequently are more resistant to interference and degradation. Although the abolition of concreteness effects in matching span (Walker & Hulme, 1999) refutes this somewhat, the re-presentation of item information means this measure is more concerned with order coding. Therefore, the precise role of the semantic system in verbal short-term memory processing remains unclear.

In addition, Walker and Hulme do not specify how intact or restored semantic traces influence subsequent serial recall processing. If items are temporarily coded in terms of their meaning, and are subject to decay and restoration, what purpose does this semantic coding serve in the retrieval process? Furthermore, the notion of temporary semantic representations being restored through a comparison with stored knowledge of word meanings is a little implausible and ill defined. Instead, any meaning-based coding of items (however this is represented) remaining active at recall could simply convey activation to support phonological retrieval, without undergoing redintegration itself. Concreteness effects would still be predicted under such an approach.

1.5.6 OSCAR

The OSCAR (OSCillator-based Associative Recall) distributed network model was developed by Brown, Preece, and Hulme (2000) as a computational system for the representation and processing of serial order. Although relevant to any field of human cognitive performance involving serially ordered information, it has been specifically applied to short-term memory. In the OSCAR model, items are represented by vectors of elements. At presentation, each item is associated with a particular state of a dynamic context signal, made up of the output of a number of oscillators of different frequencies. The overall activation pattern of this oscillators result in a context signal that specifies a unique point in time for each item.

At recall, the oscillators are reset and allowed to re-evolve, thus cueing each memory representation with its context signal. In this way, items are retrieved in their original serial position. The nature of the implemented system means that the retrieved item will be 'noisy', and may require 'cleaning up' before output. To achieve this, the OSCAR model involves a role for redintegration, through a comparison of the partial item information with a pool of possible responses. Once selected, the item is suppressed to avoid repetition.

The model accurately produces many of the effects observed in short-term memory performance, such as time effects, differential recall of order and item information, transposition gradients, and item similarity effects. It gives a detailed account of the mechanisms governing memory for serial order, and allows integration with the mechanisms of other models, such as redintegration. It also has a great potential for generality, as many aspects of the model can be applied to other forms of serial cognitive functioning.

However, OSCAR would predict inhibitory neighbourhood effects, through competition between neighbours at item recall. As output selection is based on the activation levels of possible responses, and these candidates are activated by partial item information, the more neighbours a word has the greater the competition and resulting likelihood of incorrect output selection. This is in contrast to the findings of Roodenrys et al. (in press).

Farrell and Lewandowsky (in press) have criticised the use of edge effects to explain recency, and the fact that the processes underlying serial recall have not been fully specified. They note that the mechanisms underlying the major assumptions used in the model were implemented using parameters rather than specified processes. Importantly for the purposes of this discussion, the serial order-centred nature of OSCAR inevitably resulted in a lack of specification concerning many aspects of short-term memory. The model says little concerning the actual basis of item representation and the forms of information that make up short-term memory coding.

1.5.7 Summary of Models

The models discussed adopt a variety of differing approaches to the questions posed by empirical short-term memory research. There are localist and distributed accounts of memory, such as Burgess and Hitch (1992, 1999) and OSCAR respectively. Some models are relatively simple, focusing primarily on a few elements of memory processing (e.g. redintegration), while others attempt more complex and general accounts of short-term memory as a whole. It is likely that, together, these models could provide explanations for almost all the findings uncovered in short-term memory research to date. This reflects the considerable advances made in theoretical work in recent years from a conception of short-term memory as a simple phonological loop.

It is important to note, however, that independently each model would perhaps not have the same degree of success in simulating short-term memory phenomena. The focus of each model on certain aspects of memory functioning (e.g. order representation, item representation, retrieval) at the relative expense of others means that the accounts provided by these models of some mechanisms are somewhat vague and unspecified. For example, OSCAR lays out a detailed description of serial order functioning, but has little to say on how items are represented. Similarly, although redintegration theory provides an effective account of effects such as frequency, lexicality, and concreteness (something other models often do not achieve), it does not fully address how item or order information is temporarily represented. It may be that an integration of theories would be necessary to produce a detailed account of short-term memory processing, encompassing encoding, item storage, order representation, phonological and semantic coding, and retrieval mechanisms. To enable such a model to be developed, it is important to fully explore all elements of verbal short-term memory functioning. The remainder of this chapter, and the subsequent experimental work that is reported, will examine in detail one promising area of interest that is touched on by some of the models.

1.6 Language Processing

Recent findings, such as frequency and concreteness effects, have suggested stored language knowledge and multiple linguistic coding to be important in short-term memory. As argued by R. Martin, Lesch, and Bartha (1999, p.5), '...phonological, lexical, and semantic representations are activated in both language processing as well as in verbal short-term memory.' In accordance with this, many of the models discussed so far have explicitly related aspects of temporary memory to language and speech processing. Redintegration theory was devised to account for language variable effects, and was based on speech processing principles (e.g. Hulme et al., 1997, 1999). Burgess and Hitch (1992, 1999) and Gupta and MacWhinney (1997) both proposed models in which separate input and output speech processing capacities have varying and influential roles in the temporary storage of phonological information. In the Gupta and MacWhinney model, short-term memory is functionally related to the acquisition of novel language forms (as with Baddeley et al., 1998), and is said to have a neural basis in systems existing for the processing of speech. The notion of potential connections is not a new one either, as the contents of the phonological loop were suggested to be speech-based, as was the operation of rehearsal mechanisms.

1.6.1 The Structure of the Speech Processing System

It is therefore emerging that short-term memory may be very closely allied to speech and language processing. Before further considering this possibility, it is necessary to examine the organisation of the speech processing system. The basic structure of this system will be outlined, including the different forms of information representation and how these interact in the processing of speech. As the possible mechanisms serving language perception and production would each merit several theses in their own right, this account was intended to merely provide a basic description. A schematic model of the speech processing system is presented in Figure 1.4.

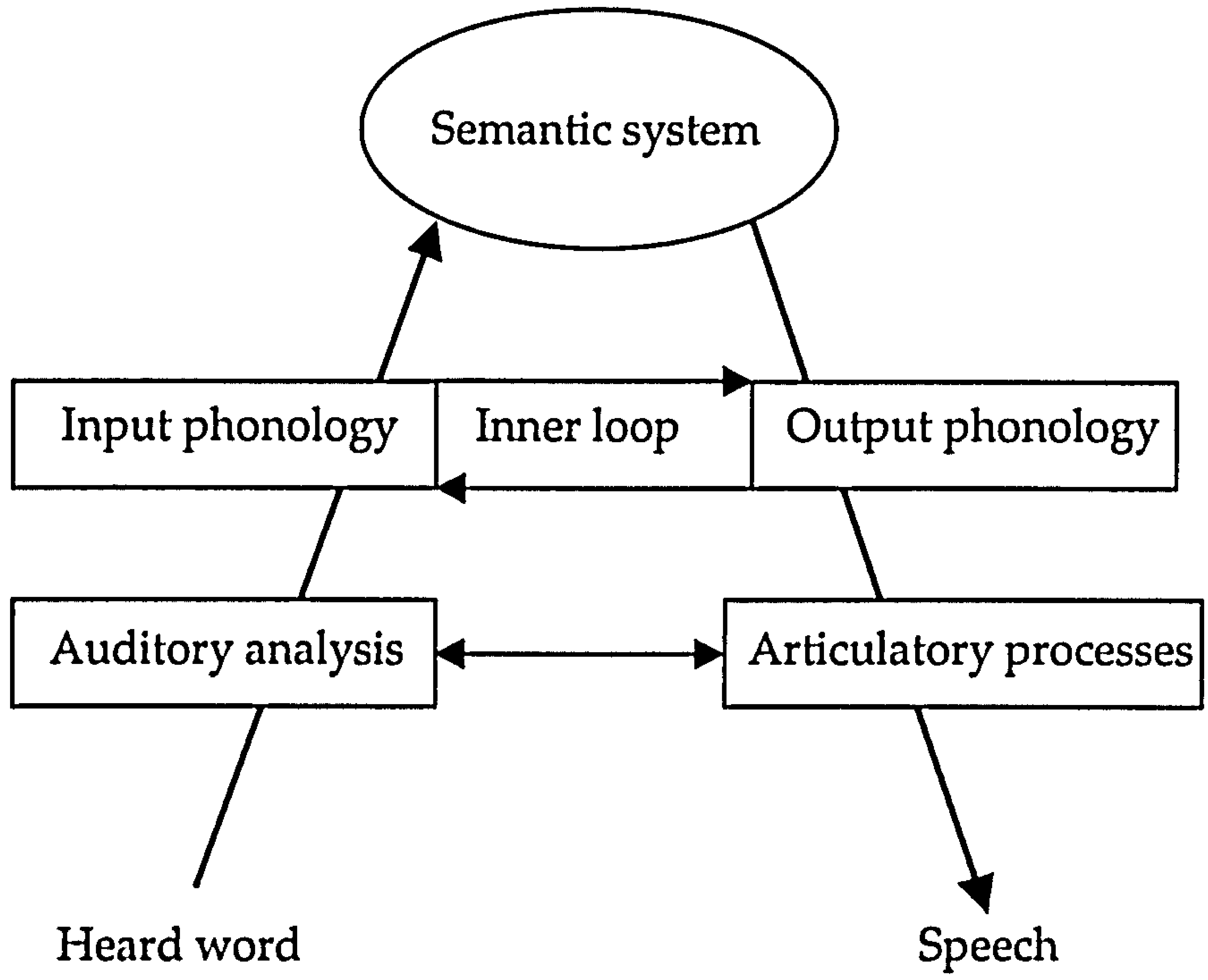


Figure 1.4. The main features of the speech processing system
Based on Monsell (1987)

1.6.2 The Input Pathway

When comprehending speech input, a temporary description of the sound of the input is formed, holding the sound of the actual speech, including stress, accent, inflection, etc. This is then compared with a lexicon of permanently stored phonological forms, a match is made, and the word is recognised. Some (e.g. Klatt, 1980) have claimed that, in the input pathway, the acoustic signal directly accesses word-level representations in input phonology. Alternatively, the acoustic-phonetic variation typically existing in the speech signal (Liberman, Cooper, Shankweiler, & Studdert-Kennedy,

1967) as a result of factors such as accent, stress, and noise, has led many to propose the need for an intermediate level of representations. Input would be split into discrete sub-lexical phonological units, possibly at a low-level involving phonetic featural information (e.g. Marslen-Wilson & Warren, 1994). Such units would normalise the input, and transmit an abstract phonological code to the input lexicon. Monsell (1987) included such a level, with separate input and output sub-lexical buffers. However, if the phonological lexicon is viewed as a distributed network, in which word-forms are represented by connections between sub-lexical segments or phonological micro-attributes (e.g. Allport, 1985), then an intermediate level is not required. Sub-lexical and lexical representation would be accomplished at the same level of encoding (as is assumed in Figure 1.4).

On the basis of activation from phonology, stored information regarding the meaning of the word is accessed in the semantic system. A number of models exist to describe the semantic processing that occurs during lexical access and word recognition. For example, the Search model (Forster, 1976) and the logogen model Morton (1969) claim that, once a word has been recognised, or distinguished from its competitors, its corresponding meaning is activated. The Cohort model (Marslen-Wilson, 1987; Gaskell & Marslen-Wilson, 1997) goes further, proposing that multiple semantic representations are activated in parallel, on the basis of the initial cohort. At input and encoding with auditory presentation, the Cohort model predicts that the meanings of all representations sharing the target words onset are activated.

It is emerging that the input pathway is highly interactive, with 'top-down' or 'concept-driven' processing occurring, through the support for low-level speech perception from stored representations in input phonology. As information enters the auditory input store and begins to spread activation through the system, lexical representations in input phonology feeds information down the system, assisting the earlier stages of perception. This process has been simulated in connectionist models such as TRACE (McClelland & Elman, 1986).

1.6.3 The Output Pathway

A mirroring of the input process is implemented when producing speech to convey meaning. A conceptual-semantic representation is produced, which accesses the required phonological information, before an articulatory-motor program is implemented. In addition, production theories describe a layer of representations between semantics and output phonology (not included in Figure 1.4), in which word level information regarding word syntax and grammar is accessed. These representations are described as 'lemmas' (from Kempen & Huijbers, 1983), containing information pertaining to the word's syntactic environment. Lemmas serve as an intermediate level, providing a relation between meaning and sound that would otherwise be arbitrary. The major models of speech production will now be outlined.

1.6.3.1 Interactive Spreading Activation Theory

One class of production theory is described as a 'spreading activation' approach (e.g. Anderson, 1983; Dell, 1986, 1988; Harley, 84; MacKay, 1987). Such models describe lexical access and output in terms of a network of connected nodes. These nodes vary in activation levels, and can convey this activation (either in excitatory or inhibitory form) to other nodes.

For example, the model proposed by Dell (1986) was organised into four levels of nodes, dealing with semantic, syntactic, morphological, and phonological information respectively. These nodes are permanently available in long-term memory, and when activated, can spread this activation to connected nodes at other levels. The route to output occurs as connected nodes are activated at each level, in a simultaneous and parallel fashion. Whole sets of nodes can be activated at a representation level, and activity can occur simultaneously at all levels. In addition, the levels have a bi-directional, interactive relationship. For example, activation can freely cascade from the morphological level to both the syntactic and phonological levels. After a node has been activated, this activation decays over time unless it is required again.

This cascading spreading activation model was shown to produce many of the speech error phenomena discussed in the literature, including malapropisms, the lexical bias effect, the repeated-phoneme effect, check-off failure, and phonemic similarity. For example, the mixed semantic-phonological error, in which the target CAT is much more likely to lead to the response *rat*, rather than to *dog* or *mat*, represents evidence for a cascading activation and feedback approach (e.g. Bredart & Valentine, 1992; Dell & Reich, 1981; Harley, 1984; Martin, Weisberg, & Saffran, 1989). It may be that the lemmas of *cat*, *rat*, and *dog* all receive semantic activation. Feedback from the phonological segments of *cat* and *rat* will then further activate the corresponding lemmas, whereas this is not the case for the *dog* lemma node (Dell & Reich, 1980; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997). The notion of interactive representational levels and concurrent semantic and phonological activation has gained recent support in the literature (e.g. Cutting & Ferreira, 1999; Damian & Martin, 1999; Griffin & Bock, 1998; Jescheniak & Schriefers, 1998).

However, the model fails to accurately describe certain properties of speech errors, and says little about the process of semantic and syntactic activation. It is also important to note that the model was not intended as an explanation of the production process and its failures, but rather as a description of speech error data (Dell, 1988; Levelt, 1989). Nevertheless, it does provide a useful insight into the possible processes of speech production.

1.6.3.2 Serial Feed-forward Theory

Levelt and colleagues (Levelt, 1989; Levelt, Roelofs, & Meyer, 1999; Levelt, Schriefers, Vorberg, Meyer, Pechmann, & Havinga, 1991; Schriefers, Meyer, & Levelt, 1990) have developed a widely acknowledged approach to the processes of speech production, primarily in response to reaction time data in production experiments. For example, Schriefers et al. (1990) administered a picture-word interference paradigm, in which participants named target pictures, whilst simultaneously being presented with auditory distractor words. By manipulating the type of distractor (semantically or phonologically related) and stimulus-onset asynchrony (SOA) of distractor and picture, Schriefers et al attempted to identify when different forms of information are activated. They observed an effect of semantic interference only at an early SOA (-150ms), and phonological facilitation only at a later SOA (+150ms). Schriefers et al. claimed this reflects the strictly separate and serial processes of lemma retrieval and phonological access during output.

Feed-forward serial models specify a very similar route to production to that proposed by Dell (1986), with processing at semantic, syntactic, and phonological levels. However, important distinctions emerge between these approaches in the connections between and within representational levels. In the Levelt et al. proposal, conceptual activation activates and selects an appropriate lemma. Although multiple lemmas can be activated, only one will be selected. Activation from that lemma only is then fed forward to the phonological level, where sound segments and metric information is specified. No feedback occurs in such an approach. For example, phonological activation does not influence semantic processing or lemma selection. Furthermore, no free cascading activation through the system occurs, so that only one level of representation is active at any time.

As it was developed primarily in response to empirical reaction time data, the Levelt et al. approach can easily account for much of this evidence.

In addition, the feed-forward spreading activation account of WEAVER++ (Levelt et al., 1999) can also describe many speech error findings. However, strict serial models of production struggle to provide an adequate explanation of some errors (e.g. the mixed semantic-phonological error), and have recently been called into question (e.g. Cutting & Ferreira, 1999; Damian & Martin, 1999; Griffin & Bock, 1998).

1.6.3.3 An Integrated Model

Dell et al., (1997) developed a model which retained the concepts of bi-directional cascading activation and simultaneous activation in multiple levels (e.g. Dell, 1986, 1988; Harley, 1984; MacKay, 1987), alongside elements of the two-stage (meaning-lemma, and lemma-sound access) approach described by Levelt and others. At the lemma level (which is viewed as essentially empty, serving as a placeholder to connect the various types of information), the most highly activated word node is selected. It then receives a large 'jolt' of activation, making it much more active than its competitors. Activation continues to spread in both directions, before the most highly activated phoneme nodes are selected (on the basis of categories such as onsets, vowels, etc). These are then linked to slots in a phonological frame.

The ordered jolts are claimed to impose seriality on the production process. Dell et al. describe their model as 'locally interactive' (Dell & O'Seahgdha, 1991), in that semantic processing has only mild effects on phonological access, and vice versa. Thus, the model describes an evolution of processing from meaning to sound over time, while also allowing for a restrained degree of bi-directional cascading activation between levels. In this way, the Dell et al. (1997) model may represent a useful 'middle ground' (p.829) between modular and interactive theories.

This model was found to be a good fit with many aspects of production performance by aphasic and control participants. Importantly, it can account for findings suggesting both seriality (e.g. Schriefers et al., 1990) and interactivity (e.g. Damian & Martin, 1999) within the process of speech production. As interactive and serial models were developed to account for fairly restricted sets of evidence (reaction time data for serial models and speech error data for interactive models), it is perhaps inevitable that a 'middle ground' theory is necessary to provide a more comprehensive explanation. Dell et al. did note the limitations of the model, such as certain word feature effects and error types it failed to describe. In particular, it did not adequately model certain effects of word length on output performance. Furthermore, the deliberate simplicity of the model leaves it open to shortcomings, to an extent. Nevertheless, the Dell et al. (1997) model is potentially useful in its attempted integration of two previously mutually exclusive approaches.

1.6.4 Interaction between Input and Output Pathways

Monsell (1984, 1987) was concerned with the speech input and output pathways, the possible connections between them, and where information may be temporarily held within this system. He discussed evidence suggesting that the input and output pathways are separable. For example, Shallice, McLeod, and Lewis (1985) observed relatively little cross-talk interference between input and output task performance. Use of the speech output system was not significantly detrimental to auditory input monitoring performance. Nickels and Howard (1995) examined input and output processing in aphasic individuals, and provided support for a similar conclusion. Thus, Monsell proposed separate buffers for the initial analysis of auditory input and the preparation of articulatory output, and independent phonological input and output lexicons, for the permanent representations of phonological information (as illustrated in Figure 1.4).

This separation of input and output pathways is thought to end at the semantic system. Evidence suggests this to be modality-independent, with the same representations involved in speech comprehension and meaningful production. For example, cross-modal priming studies show that words presented in one modality can prime recognition of related words presented in another modality (e.g. Levelt et al., 1991; Zwitserlood, 1989). In addition, there are no instances in the literature of semantic-impaired patients with clear dissociations between input and output processing (e.g. Butterworth, Howard, & McLoughlin, 1984; Martin & Saffran, 1990).

Monsell (1987) claimed that the separation between input and output phonological processing is not complete. He took the approach of Crowder (1983), to suggest the existence of two internal production-perception pathways, thus creating a non-semantic bypass. Interactive links were proposed between the phonological input and output lexicons (as illustrated in Figure 1.4). Monsell pointed to evidence indicating priming of input processing from previous generation of output phonology, such as silent mouthing of words (e.g. Gipson, 1986, Gordon & Meyer, 1984; Monsell & Banich, 1982), and the fact that we are able to monitor our own speech. These non-semantic connections appear to be bi-directional, as evidence indicates an input to output route. Some aphasic patients with impaired semantics have shown preserved repetition ability (e.g. Bramwell, 1897/1984; Martin & Saffran, 1990; Warrington, 1975), presumably based on these pre-semantic input-output connections. Similarly, patients with 'word meaning deafness' (thought to be the result of impaired input phonology-semantic connections) are still able to recognise and repeat words, without access to (also preserved) word meanings (Kohn & Friedman, 1986).

1.7 Verbal Short-Term Memory within the Speech Processing System

Many of the memory models previously discussed make theoretical connections between short-term memory and the speech and language system, and a few even place the locus of phonological storage at speech processing (e.g. Burgess and Hitch, 1992, 1999; Gupta and MacWhinney, 1997). However, the role of speech processing in short-term memory is generally not the main focus of these models, and as a result it is rarely well specified. The majority of memory models do not attempt to comment in detail how speech processing may be involved, and say little about the structure of the language system.

1.7.1 Monsell (1984, 1987)

Other researchers have made such an attempt. Monsell (1984, 1987) described the model of the speech processing system discussed above, and explicitly placed temporary verbal storage within that framework. As this approach was primarily intended as an overview of the mechanisms responsible for the perception and production of speech, the minutiae of STM phenomena were not examined in detail. Instead, Monsell described short-term memory item encoding, storage, and retrieval as being firmly couched within the speech processing system. This approach allowed both a basic discussion of the structure of the speech processing system, and a consideration of where in this system temporary verbal memory may be located.

Short-term memory was claimed to be based upon many different storage capacities, intrinsic to language processing. As later suggested by Martin and Saffran (1990), "...people rely on all levels of linguistic representation for short-term information storage and employ processing principles common to other language tasks to access and retrieve stored information..." (p.281). In particular, Monsell suggested that phonological information is stored and processed temporarily within the speech perception and production pathways, and the connections between them. Monsell (1984) described two forms of temporary representation. Temporary records of recently processed events may be based upon persisting activation in pre-existing units or links. Under this approach, short-term memory is the activated subset of pre-existing memory structures (Schneider and Shiffrin, 1977). In order to store novel information (such as nonwords), information may be stored in a limited capacity representational space separate from permanent memory, and in new connections between permanent memory structures.

Therefore, temporary representations were not seen as part of a unitary cognitive system, but instead were retained within a diverse set of language storage capacities. Monsell argued that temporary storage is associated with all the various domains of language representation, including auditory, phonological, articulatory, visual, lexical, syntactic, and conceptual information. Thus, effects of frequency, lexicality, and concreteness would emerge through the central role of these different representational forms in short-term memory storage.

Monsell (1984, 1987) primarily focused on phonological short-term memory. It is claimed that the input and output sub-lexical phonological buffers form the basis of input and output temporary phonological sequence representation. Monsell did concede that these buffers could be integrated into the input and output phonology lexicons, as suggested earlier. The non-semantic input-output phonology link would then underlie sub-vocal rehearsal, as claimed by McCarthy & Warrington (1984). Under this approach, phonological short-term memory and rehearsal would be based on input and output long-term phonological memory, and the connections between these stores. Howard and Franklin (1988, 1990) proposed a similar argument.

Monsell claimed that the pre-phonological speech input buffer and the post-phonological articulatory buffer also contribute to temporarily holding information. The former store would hold most recently heard acoustic information before it is overwritten (Broadbent, 1981), while the latter holds articulatory motor programs. The connections between these buffers would constitute an 'outer' rehearsal loop, as in silent mouthing.

The Monsell approach did not attempt to address detailed aspects of short-term memory, such as serial order coding or the precise nature of item retrieval. Instead, it represents a description of how item information of all types, but specifically phonology, may be temporarily stored within short-term buffers and permanent representations existing for the purposes of speech processing. It provides an explanation for why recent language-based effects emerge, as well as phenomena such as word length, articulatory suppression, and irrelevant speech effects. It can also account for many patterns of normal and impaired short-term memory performance.

1.7.2 Recent Developments in the Language-Based Approach to Memory

The model proposed by Gupta and MacWhinney (1997) was in accordance with many aspects of the Monsell approach. They discussed the 'opportunistic utilisation of neural structures' that takes place, with the same areas responsible for many abilities. Specifically, they discuss evidence suggesting short-term memory (and vocabulary acquisition) to function on the basis of neural areas responsible for speech processing.

Similarly, Martin, Saffran, and Dell (1996) proposed a model in which deep dysphasia and STM-based repetition disorders are variants of the same underlying disorder. They claim that repetition and STM impairments both arise from disturbances in the activation levels of temporary representations based within the speech processing system. Martin et al. suggest that "...AVSTM performance depends on storage capacities intrinsic to the language processing system." (p.83).

This approach refutes the notion of a distinctive and separable STM system. Instead, temporary verbal storage is based on speech processing mechanisms and language representations in LTM. Haarman and Usher (2001) extended this idea to semantic coding in a computational model, describing a limited capacity short-term store consisting of activated long-term memory representations. This would place temporary semantic representations within the conceptual system that serves to provide speech (both comprehension and production) with meaning. As argued by R. Martin et al. (1999, p.5), '..all levels of representation in short-term memory depend on the activation of long-term representations within semantic memory....these representations are activated at encoding and this activation is maintained during retention'.

R. Martin et al. (1999; R. Martin & Lesch, 1996; R. Martin & Romani, 1994) proposed a model (illustrated in Figure 1.5) that assumes '...a direct relation between the representations and processes involved in word perception and production and those involved in short-term memory' (R. Martin et al., 1999, p. 5). However, it does diverge from the Monsell approach in certain ways. In this model, semantic and phonological short-term retention depends on the activation of stored language representations, and the maintenance of this activation in separate short-term memory buffers.

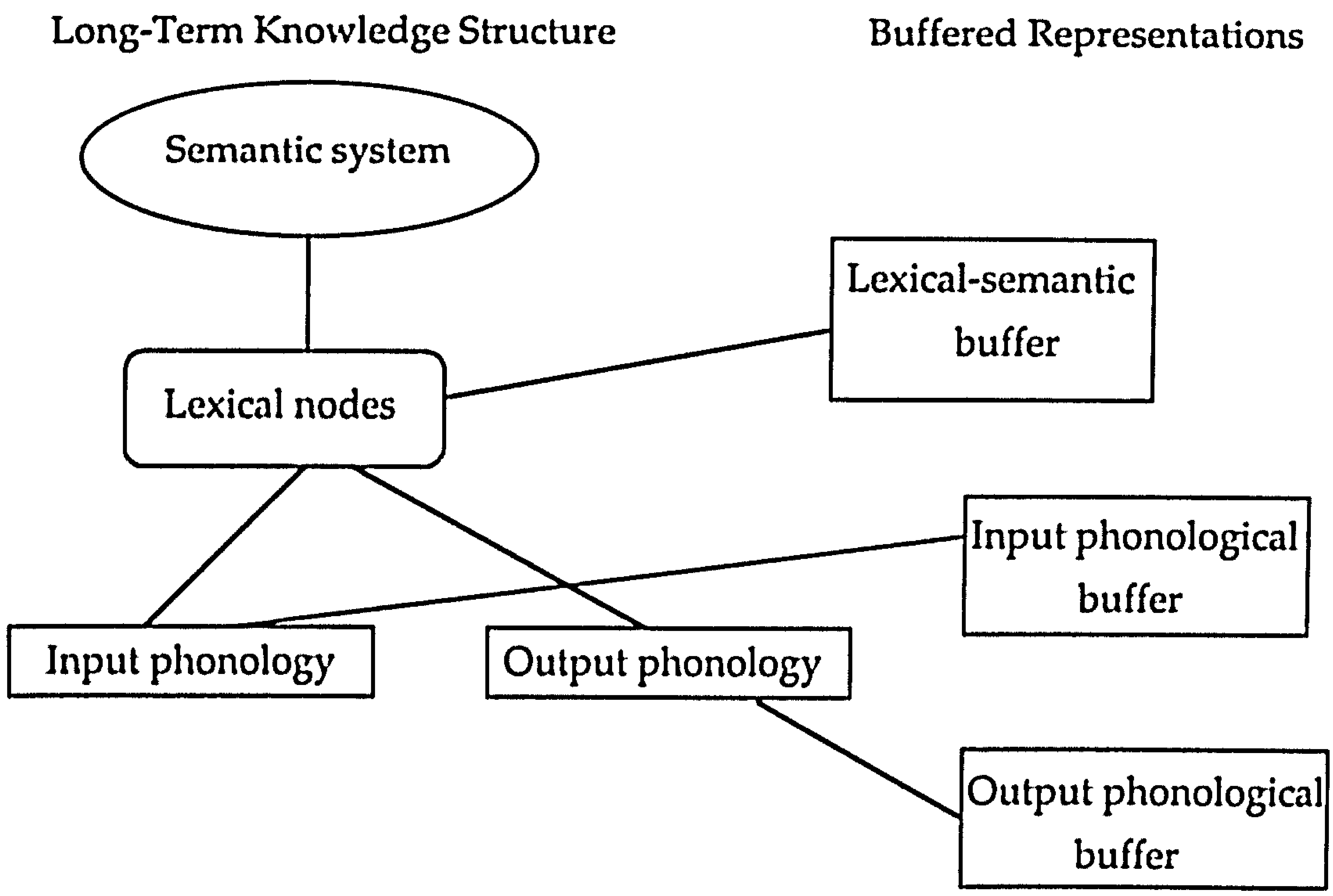


Figure 1.5. The language-based STM model of R. Martin et al. (1999)

According to R. Martin et al. (1999), representations in input phonology, output phonology, and lexical-semantics (as illustrated in Figure 1.4 and the left-hand side of Figure 1.5) are activated in memory tasks, and the results of this activation are temporarily stored in separate input phonology, output phonology, and lexical-semantic buffers. Interaction occurs between knowledge structures and buffers, with bi-directional activation links keeping long-term and short-term representations mutually active. Furthermore, buffer content reflects knowledge structure, so that variable manipulations such as frequency have similar effects in the short-term and long-term stores. Under this approach, the temporary representations underlying short-term memory are dependent on and derived from the various speech processing stores, but are separable from them, located instead within temporary information buffers.

1.7.3 The Input Pathway and its Role in Verbal STM

Language-based models describe short-term memory as being based upon multiple linguistic coding spread across a variety of independent storage capacities, all part of the speech processing system. In Immediate Serial Recall, stimuli must be initially perceived, stored, retrieved, and produced as a response. If the separable systems existing to serve input and output also underlie STM (e.g. Howard and Franklin, 1988, 1990; Martin et al., 1996; R. Martin et al., 1999; Monsell, 1984, 1987), it is possible that these speech processing pathways differentially relate to the processing of verbal information in Serial Recall tasks. It may be that input and output pathways serve different aspects of temporary memory, with one possibly more central to STM functioning than the other. If speech processing-based theories of short-term memory are to be substantiated, an attempt must be made to specify more precisely how the input and output pathways operate, and how they may relate to temporary verbal storage.

The majority of memory models that make connections to language processing have been 'input-centric'. For example, the models of Burgess and Hitch (1992, 1999) and Gupta and MacWhinney (1997) both suggested phonological information to be temporarily held as input representations. Using the Monsell (1984, 1987) approach, this would be located at sub-lexical input phonology, or the phonological input lexicon (depending on one's conception of the input pathway and the nature of the lexicon). In contrast, output processing is awarded a relatively peripheral role, concerned with rehearsal and response production operations.

Similarly, trace matching and redintegration, while thought to operate at retrieval and production, have been viewed as mechanisms involved in speech perception (e.g. Hulme et al., 1997; 1999). Virtually all auditory input can be said to differ in some way (through speech rate, accent, environmental noise, etc). Therefore, this input needs to be compared to representations in long-term phonological and semantic memory, to enable repetition and comprehension. If the input is degraded, it may be restored to completion with reference to this stored knowledge. Applying this to an input-based memory system, the process would involve interaction between the auditory input buffer and permanent representations of input phonology In contrast, it is more difficult to postulate a role for redintegration in speech production.

1.7.3.1 The Phonological Network Model

In an extension of input-centric models, Gathercole and Martin (1996) presented a model that identified the speech perception system as the sole basis of phonological memory storage. They stated that *'there is no separate temporary memory syste*m' (p.77, their italics). Instead, they claim that phonological information is represented temporarily as patterns of activation in a 'phonological network', a system existing primarily for the processing of auditory input. In response to auditory stimuli presented at input in recall tasks, phonological representations in the perception network will be activated. These will remain temporarily activated until a response is required. The network may be viewed as roughly equivalent to an intermediate sub-lexical phonological level of representations.

The wordlikeness effect is used as evidence to support the phonological network model. Gathercole and Martin claimed that the phoneme combinations of wordlike nonwords would be more efficiently represented as patterns of activation in the network, resulting in a recall advantage over nonwords with low phoneme transition probabilities. From an early age, the network becomes tuned to the phonotactic probabilities of speech, that is, how phonetic segments can be sequenced and positioned. This readiness for speech perception enables efficient and accurate word recognition and memory performance (e.g. Gathercole, et al., 1991).

Gathercole and Martin attribute lexicality and frequency effects to the system of excitatory associations between representations in the phonological network and stored knowledge in 'phonological space'. This can be viewed as the equivalent of phonological long-term memory (or the input phonology lexicon), where the sound structures of familiar words are stored. The long-term representations of familiar and frequent words (in phonological space) would provide more excitation for their component phonemes in the phonological network, and so would improve retention.

1.7.3.2 The Influence of Phonological Factors in the Input Pathway

An evaluation of potential input-based theories requires a consideration of the factors at work within the input stream described earlier. If phonological short-term memory is reliant to a large extent on perceptual processes, factors influencing immediate verbal memory should have equivalent effects on word recognition.

Lexicality

This prediction should apply to the processing of phonological input. If short-term memory is reliant to a large extent on a sub-lexical input buffer and/or the input phonology lexicon, factors influencing temporary phonological memory should have a similar effect on word recognition.

For example, an item's lexical status has an effect on how easily it can be perceived, complimenting the lexicality effects observed in recall tasks (e.g. Hulme et al., 1991). The absence of a stable representation in input phonology would result in a lack of top-down support and minimal information in long-term memory to match with the auditory input. However, an input-based memory theory must also account for the fact that participants can recall some nonwords (i.e. performance is not at zero). This would be accomplished through the activation of sub-lexical phonological representations (either separate from the input phonology lexicon, or within a distributed system as phonemic nodes).

Word Frequency

In line with an input-based memory approach, word frequency has wide-ranging effects on many aspects of language input processing. High frequency words have been shown to be easier to identify when embedded in noise than low frequency words were (Broadbent, 1967; Howes, 1957; Luce, 1986; Owens, 1961; Rosenzweig & Postman, 1957; Savin, 1963). Similarly, frequency effects have been observed in Lexical Decision (Forster & Chambers, 1973; Marslen-Wilson, 1990; Slowiaczek & Pisoni, 1986; Taft & Hambley, 1986; Tyler, Voice, & Moss, 2000). The highly active representations in input phonology that underlie much of the advantage for high frequency words in recognition tasks may also be the cause of this advantage in memory tasks. It may be that the frequency effect emerges in memory tasks at least partially through the central involvement of input phonology processing and representations.

Phonological Neighbourhood Size and Frequency

These findings suggest an important role for the input pathway in temporary phonological processing. If this is indeed the case, beneficial neighbourhood effects should also arise in recognition tasks, in line with the short-term memory findings of Roodenrys et al. (in press). However, this does not appear to be the case. Spoken word recognition models hold to the hypothesis that competition occurs between phonological neighbours, thus affecting the speed and accuracy of input processing (e.g. Luce & Pisoni, 1998; Marslen-Wilson & Zwitserlood, 1989; Norris, McQueen, & Cutler, 2000). This would predict inhibitory neighbourhood effects on word recognition. In line with this, such effects have been observed in Word Identification in noise

(Luce, 1986; Luce & Pisoni, 1998; Luce, Pisoni, & Goldinger, 1990; Treisman, 1978) and Auditory Lexical Decision (Luce, 1986).

It appears that this variable has opposite effects on perception and verbal memory performance. Common effects across tasks indicate the possibility of shared mechanisms. In contrast, evidence of a word variable influencing performance on two tasks in opposite directions provides a strong indication that the processes underlying one measure are not critical to the other. The findings of Roodenrys et al. (in press) when contrasted with recognition theory and research therefore suggest that speech input and perceptual processes may not be central to the operation of temporary verbal memory. Caution should be taken when interpreting the patterns of results drawn from two independent studies however, as the manipulation of variables was performed using different word-sets. More confident conclusions could be made if the patterns of results were replicated within a single study, using the same words on both recognition and memory tasks.

Wordlikeness as a Phonological Neighbourhood Effect

This observation of facilitatory neighbourhood effects causes problems for a perception-based approach to verbal memory. Interestingly, support for the findings of Roodenrys et al., and further evidence to suggest that input phonology processing may not be central to temporary verbal storage, can be drawn from Gathercole and Martin (1996). In an examination of the wordlikeness variable, Martin and Gathercole (unpublished) observed that participants' wordlikeness judgements were based on the density and frequency of the phonological neighbourhood occupied by a nonword. Similarly, previous research has established links between high phonotactic probability patterns and dense lexical neighbourhoods (Landauer & Streeter, 1973; Luce, Pisoni, & Goldinger, 1990). If wordlikeness effects are re-classified as a form of neighbourhood effect, perception-based STM approaches (e.g. Gathercole & Martin, 1996) are undermined by the positive influence this variable displays on recall performance (e.g. Gathercole, 1995). This facilitatory wordlikeness effect therefore indicates that verbal short-term memory performance may not be critically reliant on speech perception, as recognition research both predicts and produces inhibitory effects (e.g. Luce, 1986).

1.7.3.3 The Influence of Semantic Factors in the Input Pathway

As discussed, evidence for the notion that the speech input and word recognition pathway is at the heart of temporary phonological processing is contradictory. Nevertheless, the phonological focus of input-based short-term memory theories require extension, to account for the semantic effects recently observed in verbal short-term memory tasks. If the claim is made that temporary phonological coding is primarily based on the input (or indeed, output) phonology lexicon, it is also reasonable to suggest that temporary semantic coding is based on activation within the long-term semantic system (as suggested by Haarman & Usher, 2001). Under input-based memory theory, the mechanisms with which input phonology accesses semantic representations, and the efficiency of these processes, would govern temporary semantic coding in memory tasks. This approach therefore predicts that semantic effects, akin to those observed in recall, will also arise in tasks measuring word recognition.

Tyler, Voice, and Moss (2000) observed effects of imageability (a variable closely related to concreteness) and familiarity on Auditory Lexical Decision performance. In contrast, in a word repetition task, imageability effects were limited to words with large cohorts. Tyler et al. argued that this indicated semantic effects such as imageability to arise in the mappings between input phonology and semantics (as opposed to semantic-output mappings). An extension of this claim would be that semantic effects arise in short-term memory tasks for the same reasons, through processing within the input pathway. The interaction between word discriminability and imageability in repetition was taken by Tyler et al. to suggest that the role of the semantic system in word recognition becomes more important as processing difficulty increases.

Plaut (1997) made a similar claim, in a model of semantic and phonological processing in word reading and Lexical Decision tasks. Plaut argued that, when orthographic or phonological representations are not sufficient to support accurate Lexical Decision processing, participants rely more on activation from distributed semantic representations. This may in turn be applicable to Serial Recall performance, as temporary semantic activation acts to support phonological input processing.

As noted by Moss and Gaskell (2000), concrete words are thought to have richer semantic representations, which are accessed earlier in and provide more support for the recognition process and word identification. Plaut and Shallice (1993) proposed an interactive-activation framework, in which words vary in the number of semantic units representing them. In this model, concrete words had roughly four times as many features as abstract words. Processing concrete words in input tasks would lead to more activity in the semantic system than when abstract words are processed, and so more activation will feedback to input phonology. Furthermore, abstract words are assumed to be less stable across contexts, with a smaller amount of context-independent semantic information (Saffran & Schwartz, 1994). Such structural advantages for concrete words would produce effects in both verbal memory and word recognition tasks, should they share a common basis.

The evidence discussed so far concerning semantic effects in speech processing appears to suggest that such effects may arise in temporary memory tasks primarily through the influence of input mechanisms. Theoretical work and corresponding empirical evidence has indicated widespread and consistent semantic influences on many word recognition tasks. Therefore, if perception and STM were based on shared semantic and phonological processing mechanisms, it would be predicted that any semantic variable already shown to influence recognition would also affect temporary verbal memory.

For example Rodd, Gaskell, and Marslen-Wilson (2000) examined semantic ambiguity effects on performance in Auditory Lexical Decision. They observed facilitatory effects of related senses (faster processing of words with more senses) and inhibitory effects of semantic ambiguity (slower processing of words with more than one unrelated meaning). This constitutes a further way in which the semantic profile of a word influences recognition, in that a word with several unrelated meanings will be processed less efficiently than one with a single meaning. In turn, a word associated with a number of highly related senses, possibly clustered around a single core meaning, will be processed and recognised faster still.

Ambiguity effects on word recognition are thought to arise through semantic competition. In response to a single auditory input, two or more different and unrelated semantic patterns will be partially activated, and thus interfere with each other (e.g. Gaskell & Marslen-Wilson, 1997; Hinton & Shallice, 1991; Joordens & Besner, 1994; Plaut & Shallice, 1993; Rodd, Gaskell, & Marslen-Wilson, 2002). In contrast, facilitatory related sense effects may be similar in nature to concreteness. As with concrete words, words with many related senses can be seen as being semantically rich. This would result in faster activation of stable representations, relative to words with few senses. Such variable effects constitute further evidence of a semantic influence on input processing. Furthermore, if short-term memory were based within the input pathway, an influence of both these variables would be predicted on recall performance.

1.7.3.4 Summary

Although the speech input pathway must be involved in short-term memory performance (particularly with auditory presentation), evidence is contradictory concerning the nature of such a relationship. An input-centric model would provide an effective account of lexicality, frequency, and concreteness effects, and would be easily integrated into a specialised memory model such as Burgess and Hitch (1999), or Gupta and MacWhinney (1997). However, the pattern of phonological neighbourhood effects recently observed is at odds with a perception-based model. Similarly, several studies report patients who show preserved perceptual and recognition abilities, yet are impaired on measures of short-term memory (e.g. Knott, Patterson, & Hodges, 2000; R. Martin, et al., 1999; Patterson, Graham, & Hodges, 1994). The extent to which immediate verbal memory is reliant on the input pathway is therefore unclear.

1.7.4 The Output Pathway and its Role in Verbal Short-Term Memory

It has been established that speech and language processing may crucially influence performance on tests of verbal short-term memory. Although some have identified speech perception and input mechanisms as the more central pathway, evidence does exist to conflict with such a claim. Monsell (1984, 1987) suggested that capacities within the speech output pathway are also important in verbal short-term memory processing. Similarly, redintegration theory implies that the mechanisms underlying lexicality and frequency effects are retrieval- and output-based. It is important to consider the possibility that temporary verbal coding may primarily be based on representations within the production system. As illustrated in Figure 1.4, this is thought to involve (at a basic level) semantic activation, the output phonology lexicon, and an articulatory program buffer.

1.7.4.1 Speech Production Models and Verbal Memory

Each of the production models discussed earlier (e.g. Dell, 1986; Dell et al., 1997; Levelt et al., 1999) allow some scope for the development of a possible production-based memory model. A common trend in these theories is the processing of information at a number of distinct linguistic levels. This is particularly the case for semantic and phonological processing. Indeed, Caramazza & Miozzo (1997, p.329) described this distinction between sound and meaning as being 'as close to a universally shared position as anything is in cognitive science'. This is in accordance with recent short-term memory research. Memory performance may be based to a large extent on temporary activation across sets of output nodes, possibly at different levels of the system (as suggested by Monsell, 1984, 1987). Thus, temporary semantic coding may be located within the conceptual system, and convey activation to output phonology via lemma nodes. It may be plausible to argue that lemmas are equivalent to word level or item nodes discussed in some memory models (e.g. Burgess & Hitch, 1999). In turn, phonological short-term memory may be based to a large extent on activated output phoneme nodes placed in a phonological frame. It is at this level that frequency effects could emerge in short-term memory tasks. Forgetting would then occur through decay of node activation (e.g. Dell, 1986).

It has been argued that words are temporarily coded in terms of both meaning and sound, and that this coding is simultaneously active during storage and retrieval (e.g. R. Martin et al., 1999; Walker & Hulme, 1999). Such a claim is also central to the multiple linguistic representation approach described earlier (Monsell, 1984, 1987; Howard & Franklin, 1988, 1990). This is in direct contrast to discrete serial models of production (e.g. Levelt et al., 1999), which postulate a serial 'semantics-then-phonology' flow of activation. Interactive models (e.g. Dell, 1986; Dell et al., 1997) do overcome this problem. Semantic and phonological activation are described as simultaneous and interactive, with cascading activation feeding forward and backwards between and within representational levels. In this way, temporary coding at different linguistic levels such as semantics and phonology may be concurrently active. This represents a potentially more plausible description of how short-term memory coding may be stored and processed within the output pathway.

A common theme in the work of Dell (1986; Dell et al., 1997), Levelt (1989; Levelt et al, 1991, 1999), and others is the description of distinct representational levels serving semantics, word level information (in the form of lemmas), output phonology, and articulatory programs. If the claim is made that these information stores serve verbal short-term coding, it is necessary to look for support in the literature.

1.7.4.2 Semantics and the Path to Output Phonology

Recent work has established an important role for semantic coding in verbal short-term memory (e.g. Poirier & Saint-Aubin, 1995; Walker & Hulme, 1999). If this coding is based and processed within stored semantic representations, and impinges on the links with word nodes and output phonology, similar findings would be predicted across memory and production research.

The Effect of Semantic Variables on Speech Production

The importance of stored semantic knowledge in output processing crucially depends on task demands and the production routes used by participants. It is emerging that the importance of semantic processing in production depends upon the nature of the output paradigm used. Tasks such as Picture Naming and Definition Naming, which tap the semantics-output phonology pathway, have shown substantial effects of concreteness (Barry & Newton, unpublished), in line with Serial Recall research. The conceptual representations of concrete words would convey greater activation to subsequent levels in the production stream, facilitating selection of word level nodes and output phonology. A similar process may occur in short-term memory.

It is also possible to respond successfully in Immediate Serial Recall without support from semantic processing (via non-semantic links from input processing to output phonology). If the recall measure is relatively simple and easy to perform, participants can respond without displaying substantial influence of word meanings. However, if recall difficulty is increased (e.g. with relatively long list lengths, such as seven or more items), phonological memory processing increasingly relies upon support from semantic coding.

This argument can be applied to output tasks such as Speech Rate, Word Naming[1], and Delayed Repetition, all paradigms in which performance can proceed based on the orthographic/phonological input to output phonology route, without the need for semantics (McLeod & Posner, 1984). For example, Borowsky and Masson (1996) failed to find an effect of polysemy on naming. However, beneficial polysemy effects have been observed in naming on low frequency words (Hino & Lupker, 1996; Lichacz, Herdman, LeFevre, & Baird, 1999). If it is assumed that these polysemy effects actually reflect related sense effects as suggested by Rodd et al. (2002), the present claims are supported. It appears that polysemy/related sense effects particularly emerge in naming when phonological processing is difficult. As the connections to output phonology and the representational nodes within this system would be weak and less active for low frequency words, support from semantic processing is able to facilitate performance.

[1] Naming is often considered a measure of visual word recognition, as participants are required to read and identify the word before responding (e.g. Dempster, 1981). However, it is clear that naming tasks involve a central role for production processing, as reaction times crucially depend upon the ease with which the target item is actually retrieved and produced as a spoken response. A number of researchers have argued that naming is actually a measure of access to phonological output units (e.g. Hino & Lupker, 1996; Tehan & Lalor, 2000; Waters & Seidenberg, 1985).

Similarly, while de Groot (1989) only observed a very small effect of imageability on naming, Strain, Patterson, and Seidenberg (1995) observed concreteness effects in naming on low-frequency exception words. They suggested that 'phonological processing of regular words and high-frequency words is too efficient to allow much impact of the word's meaning' (p.1152). In contrast, Newton and Barry (1997) argued that individuals with deep dyslexia are only able to produce speech via the semantic system, so their performance on production tasks is consistently influenced by word meanings. This impairment provides an insight into production when stripped of all output routes except one that is mediated by semantics. Using a spreading activation approach, semantic representations of words are accessed automatically in all production tasks. The resulting activation support for output phonology is particularly influential when the semantics-output phonology route is the only one available (e.g. Definition Naming, or in deep dyslexia), or when phonological processing is inefficient or inadequate (e.g. on low frequency words). A semantic support approach such as this may also be applicable to immediate verbal memory.

The Tip of the Tongue Experience

One source of insight into the semantic-output phonology pathway as described by production theories can be derived from analysis of the 'tip of the tongue' (TOT) experience, a common breakdown in speech production. This phenomenon was first discussed by James (1890; 1893), and studied experimentally by R. Brown & McNeill (1966). They pioneered a method of examining TOT states, in which participants are presented with dictionary definitions, and asked to produce the corresponding word. Participants were told "If you are unable to think of the word but feel sure that you know it and that it is on the verge of coming back to you then you are in a TOT state" (p.327). The proportion of definitions eliciting TOT states remains consistent in studies (generally 5-15%), with participants often able to retrieve partial information about target words, such as first letters or number of syllables.

Many have noted the possible insights offered by TOT study. For example, Smith (1994) claimed that "from a theoretical point of view, the TOT experience may be a key phenomenon for understanding memory retrieval" (p. 28). More memorably, Brown (1991) suggested that TOT research "...has the potential to reveal subtleties of normal retrieval functions, similar to how slow-motion photography clarifies the dimensions of a hummingbird's flight" (p.204). As speech production and memory retrieval are thought to involve common processes, it may be that this output failure occurs for reasons akin to those involved in many forms of recall failure.

The insufficient activation hypothesis states that a tip of the tongue experience is elicited when the representations in output phonology are too weakly activated to be retrieved (Brown, 1991; Burke, MacKay, Worthley, & Wade, 1991). Thus, semantic and word-lemma information are activated, but output phonology does not receive sufficient activation to be fully accessed. This results in the retrieval of information concerning word meaning and grammatical and syntactic status, a feeling of knowing the word, and often the retrieval of partial phonological information (Astell & Harley, 1996). For example, studies have shown that Italian speakers experiencing TOT states are able to report grammatical gender information about the target word (Badecker, Miozzo, & Zanuttini, 1995; Miozzo & Caramazza, 1997; Vigliocco, Antonini, & Garrett, 1997).

This account of a failure in output can be extended to research in the field of short-term memory. For example, more TOT states occur when participants are attempting to retrieve low frequency or long words (Burke et al., 1991; Harley & Bown, 1998), as in short-term memory (e.g. Hulme et al., 1997). Similarly, insufficient activation problems in STM tasks (e.g. through the processing of abstract words, or through neurological impairments to the connections) have been shown to adversely affect memory performance. Although the TOT experience is not often reported by participants in short-term memory research (due to task demands and the initial presentation of phonological information) it may emerge for the same reasons as do many problems in Serial Recall, namely through insufficient semantic support for output phonology.

Phonological Production and STM without Semantic Support

The evidence discussed so far has primarily related to mechanisms underlying normal recall and production performance. Another valuable source of relevant evidence can be derived from studies of language-impaired patients. This form of research would indicate how phonological short-term memory and output processing would function, without full activation support from semantics. A number of recent studies have demonstrated that impairments to semantic support for phonological processing (whether through damage to the semantic system, or the links between semantics and output phonology) have substantial deleterious effects on both production and short-term memory.

For example, Martin and Saffran (1990) reported patient ST, who displayed a semantic impairment. Due to a consequent reliance on unsupported output phonology, ST showed severely disrupted recall performance (alongside impaired naming and relatively preserved Lexical Decision). This indicates the important roles played by various forms of linguistic information (e.g. phonology, meaning) in normal memory processing. Martin and Saffran argued that the representations underlying short-term memory and speech processing are the same. They applied the Dell (1986) interactive activation model of language production to mechanisms underpinning short-term storage and retrieval and the structure of the semantic-phonology system.

The findings of Hanley, Kay, and Edwards (2002) showed how the links between representational levels are important for STM. They discussed patient MF, who was thought to have partial impairments in the links to output phonology from both semantics and input phonology. This led to significant problems in Definition Naming, Picture Naming, Repetition, and Digit Span, alongside preserved Auditory Lexical Decision and comprehension. Such a pattern of impaired performance may reflect the structure of the underlying memory and language system. Digit span, a standard measure of short-term memory, may require the same functional system underlying Definition Naming and Repetition, but not Lexical Decision.

Patients FM (Knott et al., 2000) and MS (R. Martin et al., 1999) also had impairments in the connections between the semantic system and output phonology. FM displayed severe naming, delayed repetition, and serial recall impairments, alongside relatively preserved gating and word-picture matching performance. MS exhibited a similar pattern of preserved perception and comprehension alongside impaired production and verbal short-term memory. These patterns in themselves constitute interesting evidence for a connection between verbal short-term memory and output processing. Both FM and MS also displayed 'nameability' effects on verbal memory performance, with recall better on words they could correctly name. In contrast, no recall differences existed between words varying in ease of comprehension. In addition, FM produced many phonological errors, often involving segment migrations from previous responses, as opposed to from recent input. This was also the case with MS, who in addition produced semantic circumlocutions in list recall and naming (possibly equivalent to TOT experiences).

These findings illustrate how phonological short-term memory and output processing operate without the support of semantic activation. As argued by Knott et al., 'It is activation of the lexical-phonological representations that support *speech production* that is crucial to maintaining phonological integrity in STM' (p.139, their italics). They claim that a lack of lexical-semantic support for phonological redintegration causes many of the problems experienced by FM in memory tasks. Although R. Martin et al. (1999) chose to reject the importance of redintegration in the performance of MS, they too placed speech output processing at the centre of semantic and phonological STM. They argued that '...the same pathway that underlies retrieval of phonology from semantics in naming underlies feedback from semantics in list recall' (1999, p.3).

Semantic representations and the semantic to output phonology link appear to be highly influential, both in speech production and Serial Recall. The storage, retrieval, and production of phonological forms is more efficient for concrete than abstract words, due to the greater levels of activation conveyed from semantic representations. The studies of patients with language impairments suggest that, when this semantic support is lacking, both phonological production and short-term memory are significantly impaired. This represents interesting evidence to suggest a central role for the speech output pathway in Serial Recall performance.

1.7.4.3 Output Phonology

These results suggest that long-term semantic representations and semantic-word lemma-output phonology links may be important in temporary verbal coding and retrieval. The next question concerns the possible basis of temporary phonological representations. It may be that this coding is reliant to an extent on representations stored in the output phonological lexicon. For example, patients have been reported who have problems with the maintenance of phoneme representations following activation. This impairment is said to reveal itself through problems with speech output tasks, including picture naming and repetition. Such phoneme maintenance problems are often thought to be located at the level of the 'phonological output buffer' (Caramazza, Miceli, & Villa, 1986), thus suggesting output phonology to contain important storage capacities, possibly involved in short-term memory. This is in line with the approach set out by Monsell (1984, 1987). Conversely, although R. Martin et al. (1999) also suggested an important role for output phonology representations in STM encoding, maintenance, and retrieval, their model claimed separable output phoneme buffers to underlie much of Immediate Serial Recall. Nevertheless, each of these theories propose a pivotal role for output processing in Serial Recall is nevertheless outlined. Potential evidence in support of such an approach will now be examined.

Frequency Effects in Speech Production

An output phonology approach to phonological short-term memory would predict frequency effects in production tasks, similar to those observed in Serial Recall (e.g. Hulme et al., 1997; Roodenrys et al., 1994). This prediction is borne out by research. For example, Forster and Chambers (1973) observed greater speed and accuracy in the production of high-frequency words in a visual naming task. Similarly, frequency effects have been consistently observed in picture naming (e.g. Bartram, 1974; Griffin & Bock, 1998; Humphreys, Riddoch, & Quinlan, 1988; Huttenlocher & Kubicek, 1983; Jescheniak & Levelt, 1994; Oldfield & Wingfield, 1965; Vitevitch, 2002). It may be that this variable is influencing the operation of a common set of mechanisms in temporary verbal memory and language production.

Further support can be derived from the similar source of word frequency effects on output and recall tasks. It would be difficult to discuss such effects on these tasks in terms of support for shared mechanisms, if the effect arose for different reasons in recall and production. However, as in Immediate Serial Recall, the frequency effect is thought to emerge in production at access to long-term output phonology representations (Griffin & Bock, 1998; Hino & Lupker, 1996; Jescheniak & Levelt, 1994).

Target-related neologisms (a form of phonological approximation error) produced by aphasics in naming tasks are more common on low-frequency than high-frequency words (e.g. Caramazza, Berndt, & Basili, 1983; Kay & Ellis, 1987). Vitevitch (2002) induced more speech errors by normal participants on low-frequency words. Similarly, speech error studies indicate that phonological substitutions (e.g. "cat" for *cab*) tend to have higher frequencies than the intended words, whereas this does not apply to semantic substitutions (e.g. "cat" for *dog*) (e.g. del Viso, Igoa, & Garcia-Albea, 1991; Hotopf, 1980). The same pattern of phonological approximation errors was observed in Hulme et al.'s (1997) examination of frequency effects on serial recall, as phonologically similar responses tended to have a higher frequency than the target items.

Phonological Neighbourhood Effects in Speech Production

Beneficial effects of neighbourhood size and neighbourhood frequency on verbal memory performance have recently been observed (Roodenrys et al., in press). This contrasts with previous empirical and theoretical work concerning input processing, which predicts inhibitory neighbourhood effects. Their findings led Roodenrys et al. to refute links between recall, redintegration, and speech perception. Instead, they suggested that 'these effects of lexical neighbourhoods on recall reflect the role of speech production processes in immediate memory tasks' (p.24). Support for this proposal was derived from similarly beneficial effects of phonological neighbourhood on articulation rates.

To reiterate, the effect of phonological neighbourhood on verbal memory may arise as a direct result of the involvement of production processing. This argument is in line with claims postulating a central role for speech output mechanisms in verbal short-term memory. To support such an argument, evidence would be required showing a similar facilitatory effect of neighbourhood size and frequency on speech production performance.

Andrews (1997) reviewed the literature and observed consistently beneficial effects of both neighbourhood size and frequency on visual word naming. Similarly, Harley and Bown (1998) observed facilitatory effects on lexical access during speech production. Gordon and Dell (2001) examined the performance of aphasic patients on two production tasks, and found that word frequency and phonological neighbourhood both facilitated production accuracy. Gordon and Dell also ran 'normal' and 'aphasic' simulations of neighbourhood effects using the interactive spreading activation model (Dell et al., 1997). The model produced facilitatory neighbourhood effects on production under both normal and lesioned conditions.

Vitevitch (2002) manipulated neighbourhood size in a series of different production tasks. Fewer speech errors were induced on words from large neighbourhoods using the SLIP (Spoonerisms of Laboratory Induced Predisposition) technique developed by Baars et al. (1992; Motley & Baars, 1976) and in a tongue-twister task. Furthermore, Vitevitch (2002) observed facilitatory neighbourhood size effects on picture naming, even when controlling for phonotactic probability and ease of articulation.

These results were interpreted within an interactive production framework (e.g. Dell, 1986), as it was concluded that strictly feed-forward serial models such as WEAVER ++ (Levelt et al., 1999) would struggle to account for neighbourhood effects. Vitevitch claimed that the activated phonological nodes of the target item feed back activation to the correct semantic and lemma nodes, and all other semantic and lemma nodes relating to words containing those phonemes. As activation is then fed forward to output phonology, the phonological nodes of the target item would consequently receive activation from its own semantic and lemma representations, and those of its neighbours. Thus, activation will propagate between semantic, lemma, and phonology representations, resulting in higher levels of activation for target nodes. Such a process may underlie the facilitatory effects of neighbourhood size recently observed in speech production and short-term memory.

To summarise, empirical work has observed inhibitory neighbourhood effects on perception, and facilitatory neighbourhood effects on both production and short-term memory. Although more reliable support would be derived from facilitatory neighbourhood effects on production and memory using the same item set, this recent work is certainly in line with the idea that the output pathway may be central to temporary verbal memory performance.

1.7.4.4 The Articulatory Motor Buffer

Finally, it is important to consider the extent to which verbal information is temporarily stored in the form of articulatory motor programs. The working memory model described phonological STM as being based within the articulatory loop slave system, with a speech-based subvocal rehearsal mechanism operating to refresh traces (Baddeley & Hitch, 1974). Baddeley et al. (1975) suggested that '...the (memory) system is an output buffer....necessary for the smooth production of speech.' (p. 588). Their finding that recall varied with speed of articulation, even after controlling for abstract phonemic units, suggests an articulatory component to STM. Although subsequent research has questioned the explanatory burden placed on an articulatory loop system as the basis of verbal storage, articulatory programs may still have a role in short-term memory. For example, Monsell (1987) suggested that they might operate an outer rehearsal loop preventing information loss, via connections with an auditory input store.

Cheung and Wooltorton (2002) provided recent evidence for a possible articulatory component in short-term memory. They attempted to examine memory processes without the effects of response output, in a shadowing-plus-recall task. Following list presentation, a further item was presented which participants had to immediately shadow (repeat) before recalling the preceding list. Participants were slower to shadow words following phonologically similar lists, and tense-vowel lists (as opposed to lax-vowel lists). Cheung and Wooltorton claimed this reflected the operation of an articulatory component in STM processing, as ongoing list rehearsal interfered with articulation of shadowed items. In contrast, list frequency and lexicality did not affect subsequent shadowing performance, possibly reflecting their non-articulatory nature (as noted by Forster & Chambers, 1973), as they instead impinge on phonological processing.

1.8 Chapter Summary

It is emerging that the processes underlying temporary storage of verbal material may be more complex than previously thought. It has been established that items are temporarily coded in terms of their phonological profile, and that strategies such as rehearsal may operate on these short-term representations to prevent information loss. More recent work has uncovered other forms of linguistic coding, such as the temporary activation of word meaning and the role this information has in short-term memory performance.

In response to the increasingly detailed picture of verbal short-term memory that is being developed, many models have been put forward. These have attempted to describe various aspects of STM, including item and serial order representation, and the processes underlying encoding, maintenance, and retrieval of verbal material. An important feature of these recent models has been the connection that is often made between verbal short-term memory and speech processing. It has been suggested that temporary representations and the mechanisms operating on them may be based within the speech processing system.

It may be that the retention of verbal material is heavily reliant on storage capacities originally developed for the perception and production of speech. Further to this, an examination was made of the possible ways in which the separable speech input and output processing pathways underlie verbal short-term memory functioning. Evidence exists to suggest that various representational and processing capacities within this system may be central to many aspects of temporary verbal memory. However, the relative roles and importance of the input and output pathways in immediate verbal memory remain unclear. The possibility remains that, although all elements of the speech processing system (both perception and production) may be influential, some are more central than others.

The primary aim of the empirical work subsequently reported is to examine this issue. To this end, the basic technique in each of the experiments involved administering a range of short-term memory, perception, and production paradigms, using the same item set in each task. Recall performance on each word was then compared to ease of perception and production. In addition, it has been shown that a range of factors influence language and memory processing. Therefore, word variables were manipulated, and the resulting effects across tasks examined. It was hoped that this procedure would provide insight into how verbal short-term memory may relate to speech input and output processing.

Chapter Two

Concreteness Effects in Memory and Language Tasks

The aim of the present research is to provide insight into the potential influence of speech and language processing in short-term memory tasks. It was established in Chapter One that the successful recall of temporarily stored verbal information is dependent on stored language knowledge and speech processing mechanisms. One specific way in which language and temporary memory may interact is through the mechanism of redintegration. It has been suggested that degraded verbal coding is matched with, and restored on the basis of, long-term language representations, in a process itself thought to be speech-based (e.g. Hulme et al., 1991, 1997, 1999; Schweickert, 1993). In this way, accurate recall may be heavily reliant upon language processing mechanisms.

It may be possible to take the idea further, and describe temporary verbal coding itself as being speech-based. Monsell (1984, 1987) described a speech processing system in which verbal information can be temporarily stored in a number of separate forms, in both the speech input and output pathways. In this model, verbal short-term memory operates through activation in numerous linked storage capacities throughout the speech processing system. Some have attempted to isolate the key elements of the language system that may be involved in temporary verbal coding. For example, verbal STM has been related specifically to the speech perception system (e.g. Gathercole & Martin, 1996). In an approach such as this, short-term memory traces are re-conceptualised as the temporary activation of speech input representations.

Conversely, a body of evidence exists to implicate speech production processes in verbal short-term memory. This empirical support runs from the phonological loop theory (e.g. Baddeley, 1986; Baddeley & Hitch, 1974; Baddeley et al., 1975), through evidence of common effects on production and recall tasks, to studies of patients with impairments in short-term memory and speech production (e.g. Martin & Saffran, 1990; Knott et al., 2000). In line with these findings, recent models have emerged that place output mechanisms at the heart of Immediate Serial Recall (e.g. Martin et al., 1999).

Therefore, a debate is emerging regarding how speech perception and speech production may influence the temporary storage and retrieval of verbal information. It is this issue with which the following research is specifically concerned. The approach that was adopted in this experiment was to administer a series of short-term memory and language processing tasks. A repeated measures design was used, in that each participant performed each task, using the same word set in each. The stimuli were manipulated, and the consequent effects on Serial Recall and speech input and output task performance examined. The word variables manipulated in Experiment One were concreteness and word length.

Common effects provide useful and important empirical directions for theoretical work to follow. A potentially stronger source of 'cross-task' evidence is derived from examining how performance on different measures is connected at an individual item level. In other words, would a participant's recognition and/or production of a word predict how easily they could retrieve it in Serial Recall? The design implemented in the following experiments enables such an analysis to be performed.

2.1 Experiment One: Concreteness and Word Length in Language Processing and Verbal Short-Term Memory

2.1.1 Introduction

It can be seen from Chapter One that the existence and form of long-term phonological representations influence short-term memory performance. This is reflected in effects such as lexicality and frequency (e.g. Hulme et al., 1991, 1997). Furthermore, recent work has suggested an effect of stored semantic knowledge. Walker and Hulme (1999) observed significant concreteness effects on recall tasks. One explanation for these phonological and semantic effects is through the operation of a speech-based redintegration process, discussed earlier. It is claimed that concreteness may influence redintegration due to the comparatively rich, stable, and context-independent semantic representations of concrete words in long-term memory (e.g. Plaut & Shallice, 1993; Schwanenflugel, Harnishfeger, & Stowe, 1988). Alternatively, this processing advantage for concrete words may result in more activation being conveyed from temporary semantic representations to phonological processing, without the need for a semantic redintegration mechanism.

These language-based accounts would predict similar effects of concreteness in memory and speech processing tasks. This is indeed the case. Significant concreteness effects have been observed in measures of both input and output processing (e.g. Strain et al., 1995; Tyler et al., 2000). This suggests that the effect as it arises in short-term memory tasks is speech-based. Caution should be taken when interpreting the patterns of results drawn from two independent studies however, as the manipulation of variables was performed using different word-sets. More confident conclusions can be made if the patterns of results are replicated within a single study, using the same words on both recognition and memory tasks. The first aim of the experiment was therefore to replicate the concreteness effect as observed by Walker and Hulme (1999) in a Serial Recall task, and to examine further the cognitive basis of this effect. This was performed by administering the same word set in measures of speech perception and production. Similar concreteness effects on certain tasks may reflect a similar source of such effects, and possibly common underlying mechanisms.

The second variable to be manipulated was word length. Baddeley (1986) viewed word length effects as evidence of a speech-based, time-limited, rehearsal mechanism. Conversely, others have attributed length effects to phonological complexity (e.g. Service, 1998) or output interference (e.g. Caplan, Rochon, & Waters, 1992; Cowan, 1992). In addition, some have argued that word length may affect redintegrative processing (e.g. Brown & Hulme, 1995). Nevertheless, negative length effects were confidently predicted in Serial Recall.

An interaction between phonological and semantic processing has been observed in both perception (e.g. Tyler et al., 2000) and production tasks (e.g. Strain et al., 1995). It is claimed that, as phonological processing becomes more difficult, an increased reliance on semantic support becomes necessary for successful performance. If longer words were more difficult to process in language tasks, an increased concreteness effect would be predicted. Such an interaction may also arise in Serial Recall.

The four word sets used by Walker and Hulme, varying in rated concreteness and word length, were therefore used in this experiment. Participants completed measures of speech production, speech perception, and short-term memory, using these stimuli. Similar effects of concreteness and word length in these different tasks would reveal that a group of words generally perceived or produced well were also easier to remember. Importantly, this design also enables an examination of how a participant's performance on each word in the language tasks predicts recall of that word. This analysis would therefore reflect a more detailed examination of links between tasks, identifying possible relationships at an individual item level. It may be that results akin to a 'nameability' effect would emerge, as reported by Knott et al (2000) and R. Martin et al. (1999) in the performance of language-impaired participants. Such findings would indicate certain elements of the speech processing system to be more central to Serial Recall than others.

As noted in Chapter One, the short-term memory paradigm of interest was Immediate Serial Recall. This procedure has a number of features suitable for the present purposes. It enables an examination of how variable effects differ as a function of list position. Furthermore, the tightly controlled pseudo-randomisation procedure, in which each word is presented equally often in each serial position, enables individual item regression analyses without the confound of position effects.

Definition Naming was used as the central measure of speech production. This paradigm taps the process of phonological output access from semantic activation, as discussed by theories of production (e.g. Dell et al., 1997; Levelt et al., 1999). Although perhaps not as commonly used a task as picture naming (which obviously cannot be used with abstract words), previous research has uncovered effects of concreteness on this measure (Barry & Newton, unpublished). In addition, participants were asked to record any tip-of-the-tongue states they experienced in response to definitions, and any partial information pertaining to the word, such as initial letter or number of phonemes. The effect of concreteness on this phenomena was examined, as insufficient activation theory (e.g. Brown, 1991; Burke et al., 1991) predicts more reported TOT states during abstract word retrieval. The TOT experience may provide insight into mechanisms of word production and short-term memory recall.

Gating was selected as the measure of input processing (e.g. Cotton & Grosjean, 1984; Grosjean, 1980; Salasoo & Pisoni, 1985). This task is thought to tap the time course and efficiency of partial word input processing and recognition. Successful performance requires the selection of the full input phonology word-form on the basis of activated sub-lexical phonological representations and semantic feedback. The Cohort model (Marslen-Wilson, 1987; Gaskell & Marslen-Wilson, 1997) would predict a concreteness effect in Gating, as it is claimed that multiple semantic representations are activated on the basis of shared word onset. The phonological representations of concrete words would receive a greater boost from semantics in response to partial word information, and so would have a greater likelihood of being correctly identified.

Speech Rate was included as a final measure. This task has been viewed as an indirect measure of rehearsal rate (e.g. Baddeley, 1986; Baddeley & Hitch, 1974; Hulme et al., 1984), and so is often used as a control for the effects of such a mechanism. However, it is also reasonable to consider Speech Rate as a second measure of speech production, more phonological in nature than Definition Naming. Performance requires the repeated implementation of articulatory programs, possibly on the basis of activation from output phonology. Furthermore, Speech Rate may relate to memory through the possibility that the number of phonological units a word has may impinge on storage and on rapid repeated production. It was of interest to examine whether concreteness would effect this output measure, and how Speech Rate performance would relate to Serial Recall.

2.1.2 Method

2.1.1.1 Participants

Twenty-four University of York undergraduates took part, receiving payment or participant credit for their participation. There were 3 men and 21 women, with an age range of 18-22 years.

2.1.1.2 Materials

The item set consisted of 64 words, varying in length and rated concreteness, drawn from Walker and Hulme (1999). The set was divided into four groups of 16 words, these being one-syllable concrete words (C1), one-syllable abstract words (A1), three-syllable concrete words (C3), and three-syllable abstract words (A3). Kucera and Francis (1967) word frequency was equivalent across these groups. Full details of the word sets are provided in Appendix A.

Definitions for these words were selected from the Oxford and Collins English dictionaries and the Wordsmyth Online dictionary (Parks, Ray, & Bland, 1998). Where more than one meaning or sense was available, the most frequent and semantically relevant entry was used. The accuracy and suitability of the definitions were then rated on a scale of 1-4 by a group of independent judges (as in Harley & Bown, 1998). A two-way analysis of variance revealed a marginally significant difference in ratings of accuracy/suitability between the concrete and abstract word sets (F (1,63) =

4.07, $p < .05$), with the definitions of concrete words rated as slightly more accurate and suitable. There was no difference between the one-syllable and three-syllable items ($F(1, 63) = .000$, $p = 1.00$). The full set of definitions is provided in Appendix B.

2.1.1.3 Procedure

Participants were tested individually on all the tasks, with the same 64 words used on each. The experiment was divided into two 1hr sessions, each administered several days apart. Due to the nature of the different paradigms, each participant performed them in the same order, with Definition Naming and Gating in the first session, and Immediate Serial Recall and Speech Rate in the second.

Definition Naming (DN) Before commencing testing, participants were provided with a response sheet with three columns marked 'Answer', 'TOT', and 'Any information'. They were then given the following instructions.

> I am going to read out the definitions to around 60 words, and I want you to write down which words you think I'm referring to. If you think you have the correct answer, record it in the 'Answer' column. If you don't know what word I mean, mark it with a cross. However, if you are unable to find the word but feel sure you know it and that its on the verge of coming back to you, this is a 'tip of the tongue' experience. Tick the 'TOT' column. Make sure you are having a real tip of the tongue experience rather than merely thinking you ought to or might know the word. If you are in a TOT state and can remember something about the word, such as initial letters or number of syllables, record them in the Any Information column. If, after recording a tip of the tongue state, you remember the word, record it in the 'Answer' column.

Definitions were read out by the experimenter, with the order of presentation pseudo-randomised and counterbalanced between participants. There was no specific time limit in which to give a response and participants had the option of having each definition repeated. No feedback was provided.

Gating A digitised version of the item set, recorded by a female English speaker, was presented through an amplified speaker using a specialised gating program on a Macintosh computer. In the first round, participants received the first 100ms of each item, with each further round including an additional 50ms. Participants were required to verbally identify each item on the basis of this partial information. When an item was correctly identified, it was automatically removed from further trials. The session continued until all items had been accurately recognised. Presentation order of the words was repeatedly randomised within each block, and no feedback was provided regarding participants' performances.

Immediate Serial Recall (ISR) Testing was controlled using the Macintosh-based SerialMaster II program, using full versions of the digitised item set featured in gating. Each of the four sets of items (C1, C3, A1, and A3) were presented in their own 16 list series, with seven items in each list. Item order within lists was pseudo-randomised with the constraints that a word could not appear more than once in any given list, and that each word must be presented just once in each serial position. In addition, no two words were presented in the same order more than once (e.g. *wave* never directly preceded *net* twice for a given participant). The presentation order for the four sets of words was counterbalanced across participants.

After the experimenter initiated each trial, the seven items were presented through an amplified speaker at a rate of one word per second. Immediately after each list had been presented, participants attempted to repeat the seven items in the order in which they were presented. They were instructed to substitute the word *blank* for any items they could not recall.

Speech Rate (SR) Finally, the rate at which participants were able to articulate each of the test items was recorded. The test items were presented verbally by the experimenter one at a time, with participants being asked to repeat each one 10 times as quickly and accurately as possible. The time for each item was measured using a stopwatch.

2.1.3 Results

2.1.3.1 Summary of Task Performance

	C1	C3	A1	A3
ISR score (%)	65.16 (17.92)	55.34 (17.04)	55.19 (16.43)	41.46 (12.74)
% correct in DN	67.44 (12.22)	70.31 (10.63)	42.97 (12.81)	21.61 (12.63)
% TOT states in DN	6.51 (7.71)	6.25 (9.22)	13.02 (14.27)	18.49 (15.47)
Gating ID pt (ms)*	327.76 (16.61)	346.26 (30.18)	347.83 (19.99)	363.02 (25.33)
Speech Rate (wps)	3.13 (.34)	2.10 (.26)	3.11 (.39)	1.97 (.23)

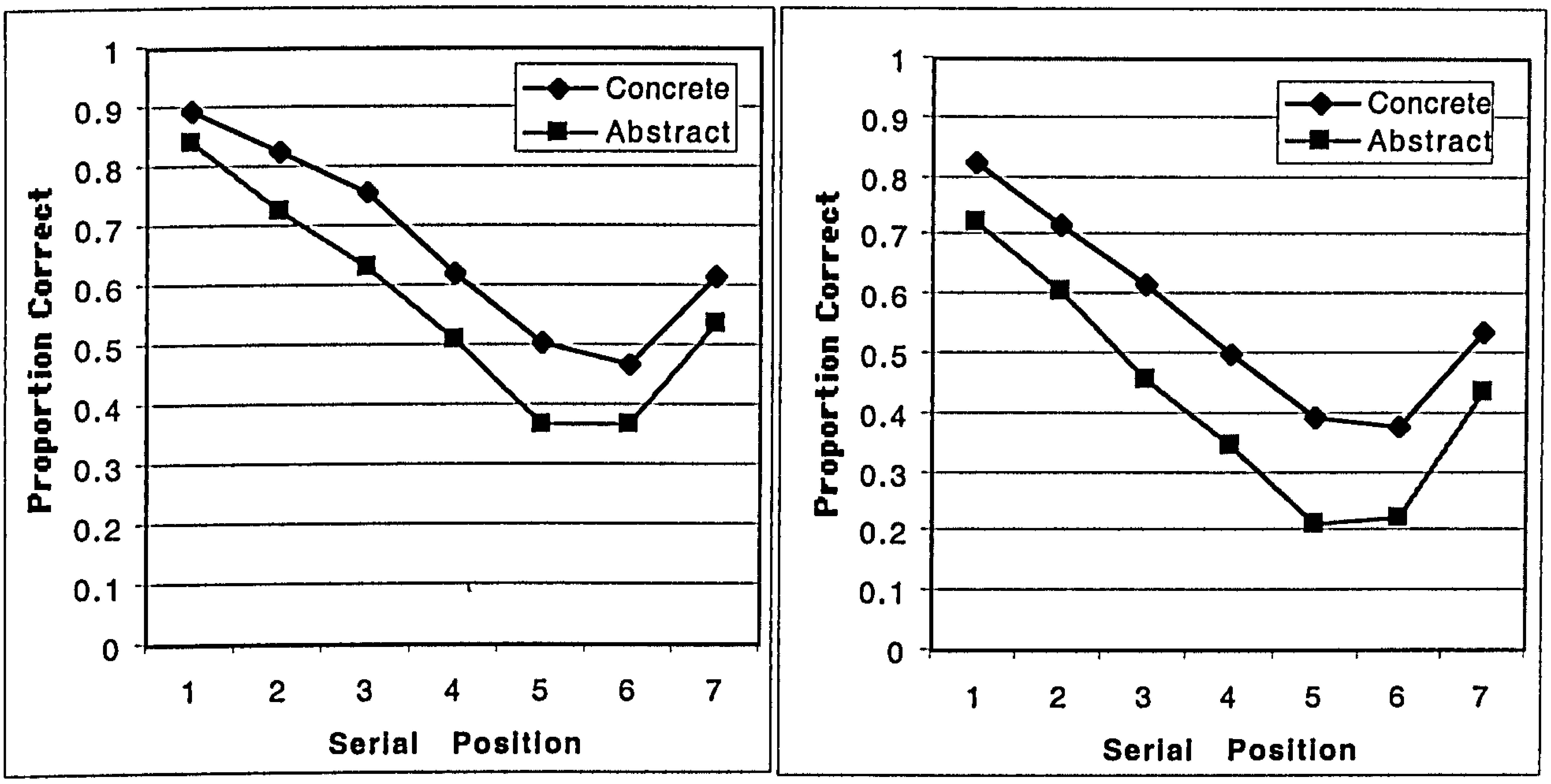
Table 2.1. Means (and standard deviations) for performance on the speech and memory tasks, on each word set.

*Gating ID pt refers to the mean time required to successfully identify an item, measured from the point of onset.

It can be seen from Table 2.1 that concreteness and length effects emerged in each of the memory and language tasks that were administered. Short and concrete words were named better to definition, elicited fewer tip-of-the-tongue experiences, were repeatedly articulated at a faster rate, and were identified more easily in Gating. Importantly, both concreteness and length effects were apparent in Immediate Serial Recall.

2.1.3.2 Immediate Serial Recall

The Immediate Serial Recall data were plotted as a function of proportion correct at each serial position (Figures 2.1 and 2.2). A bowed serial position curve is apparent for both short and long words, with a large primacy effect and a smaller recency effect. Differences between concrete and abstract words are substantial for the majority of serial positions. Furthermore, the serial position curves of short abstract words and long concrete words appear to be very similar.



One-Syllable Words **Three-Syllable Words**

Figure 2.1. Recall of one- and three- syllable words as a function of concreteness and serial position

The Immediate Serial Recall data were subjected to a three-way repeated measures ANOVA in which the independent variables were concreteness, word length, and serial position. This revealed significant effects of word concreteness (F (1,23) = 31.52, $p < .001$), word length (F (1,23)

= 45.86, $p < .001$), and serial position ($F(6, 138) = 69.17$, $p < .001$). However, the concreteness x position interaction was not significant ($F(6,138) = 1.63$, $p = .144$), nor was the length x position interaction ($F(6,138) = 1.28$, $p = .272$), nor the concreteness x length interaction ($F(1,23) = 2.29$, $p = .144$). Furthermore, the three-way interaction was also not significant ($F(6,138) = .16$, $p = .986$). Although all three factors have significant effects on recall performance, it appears that these effects are independent of one another, and that differences in recall due to concreteness and length remain equivalent across serial positions.

In order to analyse serial recall performance further, response types were categorised and converted into proportions of the total number of responses. The two basic categories were correct responses and errors. Errors were classed as order or item errors. Item errors were further subdivided into omissions (no response), extra-set intrusions (ESI: words which were not involved in the experimental item set, and do not share a substantial segment with an item presented in that list), intra-set intrusions (ISI: words involved in the item set, but not presented in the relevant list), and intra-experiment intrusions (IEI: words involved in the experiment, but not in the current list). A final category of item error were classed as phonological approximation (PA) errors, when they shared at least 50% of phonemes with an item in the presented list (e.g. response 'prize' for item PRIDE; response 'train' for item TRACE). The error patterns are displayed in Table 2.2.

The pattern of errors across the item sets was examined in a series of ANOVAs. Item and order errors are not independent, as the more words a participant can recall, the more likely order errors are to occur. It is therefore necessary to exclude the effects of item recall from measurement of order errors, by dividing the total number of order errors by the total number of list items recalled, regardless of order (Murdock, 1976; Poirier & Saint-Aubin, 1996; Saint-Aubin & Poirier, 1999, 2000). This produced proportions of order error per item recalled of .17 for C1 and .20 for C3 items, and .25 for A1 and

.30 for A3 items. A 2 x 2 repeated measures ANOVA, with concreteness and length as independent factors, revealed significant effects of concreteness (F (1,23) = 29.55, $p < .001$) and length (F (1,23) = 6.13, $p < .001$). The interaction was not significant (F (1,23) = .78, $p = .387$).

		Errors						
			Item Errors					
			Total					
Word set	Correct	Order	Item	Omissions	ISI	IEI	EEI	PA
C1	.652	.138	.211	.173	.029	.000	.001	.007
C3	.553	.175	.272	.236	.035	.000	.000	.001
A1	.552	.147	.302	.250	.033	.000	.000	.018
A3	.415	.181	.406	.364	.035	.000	.000	.005

Table 2.2. Response patterns in Serial Recall for each word set.

A 2 x 2 repeated measures ANOVA on the overall proportion of item errors revealed significant effects of concreteness (F (1,23) = 39.66, $p < .001$) and length (F (1,23) = 44.46, $p < .01$). In addition, the concreteness x length interaction was also significant (F (1,23) = 5.19, $p < .05$). A series of analyses were also performed on the item error subtypes. As extra-set intrusions and extra-experiment intrusions were of such low frequency, their distributions across word sets were not examined further. A 2 x 2 repeated measures ANOVA on omission errors revealed significant effects of concreteness (F (1,23) = 26.44, $p < .001$) and length (F (1,23) = 47.92, $p < .001$). The concreteness x length interaction was also significant (F (1,23) = 8.28, $p < .01$). This reflects the finding that more omissions were made on long and abstract words, and particularly so for long abstract words. A 2 x 2 repeated measures ANOVA on intra-set intrusion errors revealed that the effect of concreteness was not significant (F (1,23) = 0.15, $p = .705$), nor was the effect of length (F (1,23) = 0.39, $p = .537$) or the interaction (F (1,23) = 0.06, $p = .803$). Finally, a 2 x

2 repeated measures ANOVA was performed on phonological approximation error rates. This revealed significant effects of concreteness ($\underline{F}$ (1,23) = 8.62, $\underline{p}$ < .01) and length ($\underline{F}$ (1,23) = 11.72, $\underline{p}$ < .01). The interaction was not significant ($\underline{F}$ (1,23) = 1.62, $\underline{p}$ = .216).

These results indicate that words that are short and have a concrete semantic profile were better recalled due to the lower frequency of order and item errors made on those words. The main source of increased item errors on long and abstract words was a high level of omission errors. In addition, more phonological approximation errors were observed on abstract words. In contrast to this (and the overall pattern of item errors), more PA errors were observed on one-syllable items.

2.1.3.3 Analysis of Performance on the Language Tasks

Gating

A 2x2 repeated measures ANOVA was performed on the Gating data. This revealed significant effects of length ($\underline{F}$ (1,23) = 9.66, $\underline{p}$ < .01), and concreteness ($\underline{F}$ (1,23) = 21.07, $\underline{p}$ < .001) on performance. The length x concreteness interaction was not significant ($\underline{F}$ (1,23) = .22, $\underline{p}$ = .644).

A 2x2 by-items ANOVA was also carried out. This revealed no significant effects of concreteness ($\underline{F}$ (1,63) = .732, $\underline{p}$ = .396) or length ($\underline{F}$ (1,63) = .612, $\underline{p}$ = .437) on Gating performance. The interaction was also not significant ($\underline{F}$ (1,63) = .006, $\underline{p}$ = .939).

Definition Naming

A 2x2 within-participants ANOVA on correct responses in Definition Naming, with word length (1 and 3 syllables) and concreteness (concrete and abstract) as variables, revealed significant effects of concreteness ($\underline{F}$ (1,23) =

188.73, $p < .001$) and length ($F(1,23) = 17.70$, $p < .001$), and a significant interaction ($F(1,23) = 48.58$, $p < .001$).

The items analysis also revealed a significant effect of concreteness on correct responses in Definition Naming ($F(1,63) = 36.80$, $p < .001$). However, the effect of length was not significant ($F(1,63) = 2.38$, $p = .128$). The concreteness x length interaction was significant ($F(1,63) = 4.09$, $p < .05$). As there was a marginal difference in definition accuracy/suitability between the concrete and abstract items, an ANCOVA was performed on the data with definition rating as the covariate. The effect of concreteness on correct response rates remained significant ($F(1,63) = 30.18$, $p < .001$), while the length effect was not significant ($F(1,63) = 2.70$, $p = .106$). The interaction remained significant ($F(1,63) = 4.63$, $p < .05$).

Next, participants' reported tip-of-the-tongue states for each definition were analysed. The 2x2 within participants analysis revealed a significant effect of concreteness on TOT elicitation rates ($F(1,23) = 21.41$, $p < .001$). However, the effects of length ($F(1,23) = 1.46$, $p = .240$) and the concreteness x length interaction ($F(1,23) = 2.28$, $p = .145$) were not significant.

A similar pattern was produced by the items analysis. The effect of concreteness on TOT states caused by each item was significant ($F(1,63) = 23.13$, $p < .001$). In contrast, there was no significant length effect ($F(1,63) = 2.16$, $p = .147$), nor was the concreteness x length interaction significant ($F(1,63) = 1.79$, $p = .187$). The ANCOVA with definition rating as the covariate revealed a significant effect of concreteness ($F(1,63) = 19.92$, $p < .001$), but not of length ($F(1,63) = 2.14$, $p = .149$) or the interaction ($F(1,63) = 1.77$, $p = .189$).

Speech Rate

A 2x2 within-participants ANOVA was performed on the Speech Rate data, revealing significant effects of concreteness ($F(1,23) = 87.16$, $p <$

.001), length (F (1,23) = 522.34, p < .001), and the concreteness x length interaction (F (1,23) = 81.69, p < .001).

A 2x2 by-items ANOVA revealed a significant effect of length (F (1,63) = 375.00, p < .001) but not concreteness (F (1,63) = 1.55, p = .218). The interaction was not significant in this analysis (F (1,63) = .637, p = .428).

To summarise the pattern of results revealed by these analyses, word length had significant effects on performance in each of the memory and language tasks administered. Participants performed consistently better on shorter than longer words. In addition, large concreteness effects were observed in Serial Recall and Definition Naming (both correct and TOT rates). Effects of this variable were also apparent in Gating (in the participants analysis) and on three syllable words in the Speech Rate task.

2.1.3.4 Analysis of Relationships between Language Processing Measures and Immediate Serial Recall

The data were entered into what has been termed a 'Method 3' regression analysis (Lorch & Myers, 1990), a form of analysis that considers participant as well as item variance. This type of analysis establishes whether within participants there are reliable associations between the dependent variable (recall) and independent variables (measures of language processing). A simultaneous linear regression was performed using this method. For this experiment, item length (ms), Definition Naming, Speech Rate, and Gating were entered into the equation, with ISR performance as the dependent variable. Item length was entered into the regression model for a number of reasons. Firstly, it enables an analysis of links between memory and language performance, with the large effect of the word length manipulation controlled. Secondly, it is important to control for any other variations in item length both between and within item sets. It is also of interest to examine the extent to which recall performance is predicted by the spoken length of each item. The results are displayed in Table 2.3.

Variable	t	Unique R_2	Sig t
Item Length	-2.572	.003	.0102
Definition Naming	3.691	.007	.0002
Speech Rate	6.465	.021	.0000
Gating	-.218	.000	.8278

Table 2.3. Within-participant item regression analysis with Serial Recall as the dependent variable

The regression analysis reveals that Definition Naming, Speech Rate, and item length predict unique variance in recall performance. In other words, the more likely a participant was to produce an item to its definition, the greater the likelihood of them correctly recalling it in Serial Recall. Similarly, the speed with which a participant was able to repeatedly articulate a word directly predicted recall of that word. In addition, each participant's recall performance was indirectly proportional to item length. Gating performance did not predict unique variance in Serial Recall.

2.1.4 Discussion

In this experiment, the recall of words varying in rated concreteness and length was related to performance on those words in input and output tasks. Significant effects of both word length and concreteness were observed on short-term memory performance, in that short and concrete words were better recalled than long and abstract words. In Definition Naming, large concreteness effects were apparent on correct response rates and on reported tip-of-the-tongue experiences. Performance was particularly poor on long abstract items. While the predicted effect of word length was apparent in Speech Rate, concreteness effects also emerged on three-syllable items.

Significant effects of word length and concreteness were also apparent in the Gating task.

All the data were then entered into a within-participants regression analysis to examine the factors related to probability of successful recall. This revealed that both Definition Naming and Speech Rate performance predicted Immediate Serial Recall, even when item length was entered as a predictor. The more likely a participant was to name a word to its definition, and the quicker a participant was to repeat a word, the greater the probability of correct recall. Item length also predicted unique variance in recall performance. In contrast, Gating performance did not account for unique variance in participants' recall of items.

These findings have a number of important implications. The concreteness effect observed in recall performance indicates an influential role for semantic processing in verbal short-term memory, supporting the class of model that proposes multiple language-based storage capacities (e.g. Monsell, 1984, 1987; R. Martin et al., 1999). It may be that, as claimed by Walker and Hulme (1999), items are coded in terms of meaning and that this semantic coding supports redintegration at response production. Alternatively, temporary semantic coding may not contribute to a redintegration process, but instead simply serve to support phonological output processing throughout retention and retrieval.

Evidence for such a semantic support theory may be derived from the error analysis. Although relatively uncommon, phonological approximation errors were more common on abstract items. This is in line with the arguments of Knott et al. (2000), who claimed that impaired (or in this case, a low level of) semantic activation conveyed to phonological processing can lead to such errors in recall tasks.

Furthermore, the positive effect of length on such error rates is consistent with the Brown and Hulme (1995; Hulme et al., 1999) claim, that a redintegration process would be more useful and accurate for longer words. The partial loss of phonological information from short words would be more likely to produce approximation errors, as degraded traces are incorrectly matched to a phonological neighbour. Longer words typically have fewer neighbours and would suffer less from partial degradation.

Overall though, word length did have the predicted negative effect on performance. Controversy has emerged recently concerning the locus of such effects. While Baddeley et al. (1975) originally attributed them to the temporally limited capacity of the articulatory loop and rehearsal, others have postulated interference through output degradation as the source (e.g. Cowan et al., 1992; Dosher & Ma, 1998). Alternatively, word length effects may reflect greater phonological complexity (Caplan, Rochon, & Waters, 1992; Service, 1998, 2000). Although the present results do not clearly differentiate between such theories, they suggest output interference not to be the single underlying cause, as length effects did not interact with serial position.

It is of interest to examine how concreteness and word length interact in Serial Recall. At first glance there does not seem to be an interaction, as these variables had independent effects on correct response rates. However, interactions are apparent on item error rates, specifically omission errors. Participants produced comparatively more omission responses on long, abstract words. This would suggest that the increased semantic support provided by concrete words particularly facilitates phonological storage and retrieval when this process is difficult.

Word length influenced order error rates, as found by Walker and Hulme (1999). However, in contrast to their findings, concreteness also influenced the rate of order errors. This does not necessarily suggest the semantic system to have a direct influence on memory for order though. As noted, more item errors were made on abstract word lists. An item error made early in a list is likely to disrupt the recall of later items, producing further item errors and also order errors. For example, the participant may forget the fourth word in the list, and so recall each of the remaining items a position too early. Alternatively, the extra cognitive effort required to produce an abstract word may take valuable processing resources away from subsequent list items, affecting both order and item coding. In this way, concreteness would influence order error rates without influencing order coding itself.

It is important to relate the recall data to the findings from the language tasks. The substantial concreteness effects observed in Definition Naming indicate an influential role for semantic processing in speech output mechanisms, as predicted by models of production (e.g. Dell, 1986; Dell et al., 1997). The phonological forms of concrete words would be easier to access and produce, due to high levels of well-defined activation being conveyed from semantic representations to output phonology. This interaction may also result in the advantage for concrete words in Serial Recall.

Similarly, the effect of concreteness on tip-of-the-tongue states in Definition Naming supports insufficient activation theories of TOT (e.g. Brown, 1991; Burke et al., 1991). According to this approach, lower and less accurate levels of activation would be conveyed to output phonology from abstract semantic concepts and lemma representations, increasing the likelihood of an incomplete production process. These mechanisms may also underlie the increased probability of memory failure on abstract words in Serial Recall. As concreteness has a substantial influence on output processing critical to Definition Naming, it is possible that such effects arise in Serial Recall for the same reasons.

The significant concreteness x length interactions in both output tasks (Definition Naming and Speech Rate) are in line with the claims of Strain et al. (1995) and others, and the results observed in the Serial Recall error analysis. When phonological processing is more difficult (e.g. with longer words), semantic support becomes increasingly important to speech production and temporary verbal memory. The finding that semantic activation does affect processing in a primarily phonological production task indicates it to have a pervasive influence throughout the output pathway. This would appear to be more consistent with interactive activation models of production (e.g. Dell, 1989; Dell et al., 1997).

Semantic processing also appears to influence speech perception and word recognition, as evidenced by the concreteness effect observed in Gating. These findings are in line with the predictions of the Cohort model (Marslen-Wilson, 1987; Gaskell & Marslen-Wilson, 1997), as the phonological representations of concrete words would receive a greater boost from semantics in response to partial word information, and so would have a greater likelihood of being correctly identified. This would also suggest concreteness effects to arise in Serial Recall at least partially through the operation of speech input mechanisms, should these capacities be important to verbal short-term memory. This would specifically occur in interactions between input phonology and the conceptual system. It is worth noting, however, that the effect in Gating was less substantial than those observed in Serial Recall and Definition Naming, and was only significant in the participant analysis.

A number of similarities are apparent between performance in Immediate Serial Recall and speech processing tasks. The effects of word concreteness and length that were observed in the language tasks support the notion that these effects as they arise in short-term memory are the result of speech processing mechanisms. Although the results do not allow a firm specification of how input and output processing may differentially contribute to concreteness and length effects, the relative magnitude and robust nature of the effects in Definition Naming indicate the capacities underlying this task to be more influential. Similarly, the size of the length effects in Speech Rate would suggest the outcome this variable has in short-term memory to be production-based.

Evidence that output representations may be more critical in verbal short-term memory than input representations comes from the regression analysis. The finding that recall performance is significantly and independently predicted by two very different output tasks suggests the production pathway to have an important role in temporary verbal memory. The significant variance predicted by Speech Rate cannot be attributed simply to length or complexity effects, as spoken item length was also included in the analysis (and was not significant).

Under production theory terminology, Definition Naming can be said to primarily tap access to output phonology, from initial semantic activation. Speech Rate performance involves interaction between temporary phonological output representations and articulatory processing. The regression results suggest that the processing capacities critical to both of these measures of speech production are also important to verbal short-term memory. In contrast, it is difficult to account for these results with an input-based theory, as Gating performance was not related to recall. These findings are analogous to the nameability effects reported by Knott et al. (2000) and R. Martin et al. (1999) in language-impaired patients' Serial Recall. In those studies, participants showed a recall advantage for words that they were able to correctly produce in picture naming, whereas no memory differences were apparent between words varying in ease of comprehension.

2.2 Concreteness in Children's Language and Verbal Short-Term Memory Performance

2.2.1 Introduction

It has been established that concreteness influences verbal short-term memory and speech processing performance of adults. Furthermore, regression analyses indicated that STM may have a closer relationship with speech output than with speech input mechanisms. This study investigates whether the findings of Experiment One can be generalised to children's cognitive abilities. Although the development of verbal short-term memory and the speech processing system in children is not the main focus of this thesis, it is useful to see if patterns of adult performance can be replicated in children. If close functional links do exist between verbal STM and speech processing, it would be plausible to assume the emergence of similarly close ties in the developing language system.

Firstly, it is important to explore whether findings from an adult population have been replicated in children, and subsequently examine in turn whether these findings can be replicated and extended in the present study. Roodenrys, Hulme, and Brown (1993) observed lexicality and length effects in children's STM performance, thus extending the findings of Hulme et al. (1991) and suggesting that stored language knowledge does influence recall in children as well as adults. Nation, Adams, Bowyer-Crane, and Snowling (1999) replicated these findings and, importantly for this study, also observed concreteness effects in the short-term memory performance of a group of nine-year olds. Interestingly, they observed a particularly low probability of abstract word recall in poor comprehenders, relative to normal readers. This was taken as support for the notion that verbal memory performance reflects the operation of underlying speech perception, production, and comprehension mechanisms. As poor comprehenders have problems with semantic information, they will receive little 'boost' in activation for phonological processing for abstract words.

The claim made by Nation et al. (1999) that variation in children's recall as a result of concreteness, lexicality, and length reflects the operation of speech and language processing mechanisms will be explored in this experiment. The influence of concreteness will be examined, not only in verbal STM, but also in tasks measuring aspects of speech perception and production. If concreteness effects in children's Serial Recall do result from the role of such cognitive language processes (as argued by Nation et al., 1999, and others), then similar effects would be predicted in measures such as Gating and/or Definition Naming. An empirical investigation of whether these findings can be replicated and extended to speech processing tasks would also allow an evaluation of other recent theoretical work postulating connections between developing verbal memory and other language processes and mechanisms. Findings indicating links between short-term memory and speech and language ability will have implications for such models.

One widely discussed link involves the possible connection between verbal memory and speech rate. Baddeley (1986; Baddeley & Hitch, 1974) placed this relationship at the centre of STM functioning, based on a number of findings linking memory span with articulation speed in children and adults (e.g. Baddeley et al., 1975; Hitch & Halliday, 1993; Hulme et al., 1984; Naveh-Benjamin & Ayres, 1986; Schweickert & Boruff, 1986). Such observations have been taken to reflect the efficiency of a rehearsal process, whereby verbal information is repeatedly rehearsed in order to reactivate it and prevent decay. This represents one way in which production mechanisms may be vital for short-term memory. If children were not able to effectively rehearse words as measured by Speech Rate (possibly due to inefficient speech output operation), Serial Recall would be adversely affected.

Verbal short-term memory has also been linked to vocabulary acquisition in children (e.g. Baddeley et al., 1998; Gathercole & Adams, 1993, 1994; Gathercole et al., 1997; Gathercole & Martin, 1996; Gupta & MacWhinney, 1997; Michas & Henry, 1994). Baddeley et al. (1998) argued that the ability to temporarily store novel phonological information is vital for the permanent construction of memory representations. Conversely, Gupta and MacWhinney (1997) proposed a non-causal model, describing vocabulary acquisition and verbal short-term memory as a shared system, with a mutual basis in the neural areas involved in speech processing. In the Gathercole and Martin (1996) approach, phonological STM is based within the speech perception system, and has a causal effect on vocabulary acquisition. It was hoped that administering measures of verbal memory, speech perception, and speech production, along with standardised tests of vocabulary knowledge, would provide insight into this proposed relationship. If children's verbal short-term memory skills and vocabulary acquisition are indeed connected, what role might the speech processing system have?

Therefore, a similar procedure was adopted to that featured in Experiment One. The same one-syllable words, manipulating concreteness, were presented in Immediate Serial Recall, Definition Naming, Gating, and Speech Rate, with the aim of replicating the pattern of findings previously observed in adults, and exploring developmental relationships between measures of STM and language processing.

2.2.2 Method

2.2.2.1 Participants

The sample consisted of 40 children (22 boys, 18 girls) aged 7:10 to 11:11 (mean 9:10), with a mean age-equivalent reading score of 9:9 on the BAS II. All children attended schools in the York area.

2.2.2.2 Materials

The three-syllable words were removed from the item set used in Experiment One, because they were not controlled for frequency in children, and would have proved difficult for the children to deal with in many of the tasks. The 32 one-syllable concrete and abstract words were retained as frequency for children was controlled.

The definitions were altered in that, while the language was simplified, the same core meanings for each word, as used in Experiment One, were retained. This ensured that children were attempting to access equivalent semantic representations, with the same degree of difficulty, to those accessed by the adults. For a list of the definitions used in this experiment, see Appendix C.

2.2.2.3 Procedure

The children performed all the tasks, with the same word set used in each measure. They were seen individually on three separate occasions. In the first session, standardised measures of reading ability (BAS II single word reading test) and vocabulary knowledge (WISC III-R) were administered, along with the Definition Naming task. Gating was administered in the second session, while the final session involved Immediate Serial Recall and Speech Rate. Sessions were carried out on separate days, with intervals of several days between each time of testing, thus reducing any order effect confounds caused by the necessary serial presentation order of the tasks.

Definition Naming (DN) Children were provided with a response sheet similar to that used in Experiment One, before testing begun. In addition, the instructions provided were a simplified version of those used in the previous experiment (see Appendix). . It was decided that the 'tip of the tongue' state was a very difficult and complex idea for the participants, particularly the younger children, to fully understand. It was therefore not recorded in this experiment. Definitions were presented aurally by the experimenter, in a pseudo-randomised and counter-balanced order. Participants had the option of having definitions repeated, and any language that children were unsure of was explained (although care was taken not to provide any further information about the answer). Participants responded verbally, and were then asked to write their answers on the response sheet (with the assurance that accuracy of spelling was not important). No specific feedback regarding the child's performance was provided at any stage

Gating The procedure and the digitised one-syllable words used in Experiment One were used in this experiment. However, in order to reduce difficulty and participant fatigue, the first two blocks of each of the 32 items were removed from the program. This meant children were initially given 200ms of each word (as opposed to 100ms in Experiment One), with 50 additional ms for each subsequent trial. The task was presented through an amplified speaker using a portable Macintosh computer. Again, no specific feedback was provided regarding performance.

Immediate Serial Recall (ISR) Testing was performed with a portable Macintosh computer, using the full versions of the digitised stimuli featured in Gating. Each of the two word sets was presented in a sixteen list series, with five items in each list. The presentation procedure and pseudo-randomisation constraints used in Experiment One was again implemented.

Speech Rate (SR) Finally, the rate at which participants could repeatedly articulate each word was recorded, using the procedure described in the previous experiment.

2.2.3 Results

2.2.3.1 Summary of Task Performance

	Concrete	Abstract
Immediate Serial Recall (%)	53.75 (20.19)	46.03 (18.84)
Gating ID Point (ms)	425.39 (25.88)	465.86 (31.11)
Definition Naming (%)	62.03 (12.85)	21.88 (14.57)
Speech Rate (words/sec)	2.69 (.58)	2.66 (.55)

Table 2.4. Means (and standard deviations) for performance on the speech and memory tasks, on each word set.

It is apparent that the pattern of results displayed in Table 2.4 suggest similar trends to those observed in Experiment One. Namely, performance on concrete words appears to be superior to that on abstract words in Definition Naming, Gating, and Immediate Serial Recall measures. However, in this experiment, there appear to be no differences between item sets in Speech Rate. It is unlikely therefore that concreteness effects in other tasks are attributable to differences in Speech Rate.

2.2.3.2 Immediate Serial Recall

Serial Recall performance is illustrated in Figure 2.3, as a function of concreteness and serial position. Bowed serial position curves are apparent for both item sets, with large primacy effects and smaller recency effects. Differences between concrete and abstract word recall only appear in the final three list positions.

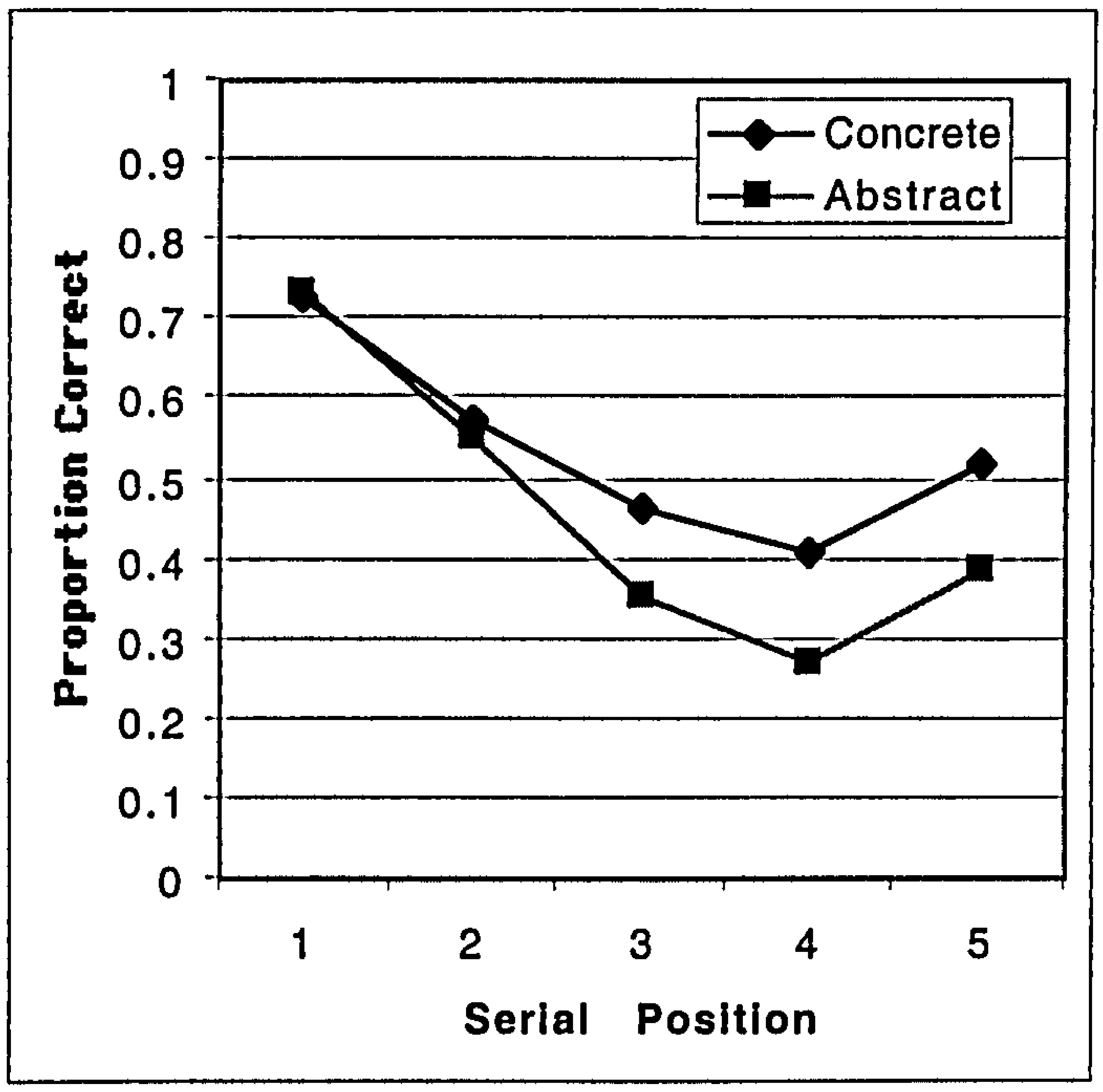


Figure 2.2. Recall as a function of concreteness and serial position

A 2x5 repeated measures ANOVA was performed on the Serial Recall data, with concreteness and serial position as the variables. This analysis produced significant effects of concreteness (F (1,39) = 16.77, $p < .001$) and serial position (F (4,156) = 50.48, $p < .001$) on recall performance. Furthermore, the concreteness x serial position interaction was also significant (F (4,156) = 6.05, $p < .001$). Analysis of simple effects showed that the concreteness effect was not significant at the first (F (1,39) = .08, $p = .781$)

or second (F (1,39) = .62, p = .435) list positions, but was significant at the final three positions.

In order to reveal more about the influence of concreteness on Immediate Serial Recall, an examination of response types in this task was undertaken. Responses were initially classed as correct or incorrect, with incorrect responses being divided into order and item errors. A further distinction was made in the types of item error, with such responses being categorised as omissions, intra-set intrusions, intra-experiment intrusions, extra-experiment intrusions, or phonological approximation errors. Descriptions of these error types are provided in Experiment One. The results of this analysis can be seen in Table 2.5.

		Errors						
			Item Errors					
Word set	Correct	Order	Total Item	Omissions	ISI	IEI	EEI	PA
C	.538	.186	.273	.197	.050	.004	.000	.022
A	.460	.174	.367	.263	.040	.001	.001	.062

Table 2.5. Response patterns in Serial Recall for each word set

As already discussed, participants made a greater proportion of correct responses on concrete than abstract words. Also, there were more order errors made in total on concrete words, although this difference is small. The proportion of order errors per item recalled was .26 for concrete words and .27 for abstract words, indicating there were no reliable differences in the rates of order errors between these item sets (t (39) = 0.91, p = .370). This contrasts with the significant effect of concreteness on order errors observed in Experiment One.

It is apparent that participants made a greater number of item errors on abstract than concrete words (t (39) = 5.81, $p < .001$). When item errors were divided into subtypes, there were a greater proportion of omission errors made on abstract than concrete words (t (39) = 3.67, $p < .01$). There was also a non-significant trend for more intra-set intrusion errors to be made on concrete words (t (39) = 1.72, $p = .093$), replicating the finding in the first experiment. The proportion of phonological approximation errors made by participants in Experiment One was around 1-2% on this item set. However, with children, this form of error appears to have a greater frequency. In particular, a substantially larger proportion of the responses to abstract words involved phonological approximations (t (39) = 9.02, $p < .001$). In order to compare the rate of approximation errors in adults and children, a 2x2 ANOVA was performed on this data and the error rates on the same one-syllable items in Experiment One, with age group as the between-participant variable and concreteness as the within-participant variable. This revealed significant effects of concreteness (F (1,62) = 53.62, $p < .001$), age group (F (1,62) = 20.55, $p < .001$), and the interaction (F (1,62) = 17.04, $p < .001$). As in Experiment One, intra-experiment and extra-experiment intrusion error rates were very low and so were not examined further.

Unlike Experiment One, the improved recall of concrete words appears to be the result of lower item error rates only, with order error rates remaining unaffected by the semantic profile of the test materials. For the children in Experiment Two, the relatively poor Serial Recall performance on abstract words can be attributed to the increased likelihood of participants failing to produce a response, and incorrectly responding with a word that is phonologically similar to the target item. Children also made significantly more approximation errors than adults, particularly on abstract word lists.

2.2.3.3 Analysis of Performance on the Language Tasks

Gating

In the participants analysis, a two-tailed paired t-test revealed a significant effect of concreteness on Gating (t (39) = 8.28, $p < .001$). This was not significant in the items analysis (t (30) = 1.33, $p = .194$). However, when spoken item length (length in ms of each stimuli) was entered as a covariate in a by-items ANCOVA, concreteness was shown to have a significant effect on Gating (F (1,31) = 8.94, $p < .01$).

Definition Naming

Across participants there was a significant effect of concreteness on Definition Naming (t (39) = 19.59, $p < .001$). The same pattern was true in a by-items analysis (t (30) = 4.05, $p < .001$).

Speech Rate

There were no significant differences in Speech Rate between concrete and abstract words in the participants (t (39) = 1.08, $p = .288$) or items (t (30) = .078, $p = .782$) analyses.

2.2.3.4 Individual Differences Analyses

As much research is focused on developmental changes in various cognitive language abilities, and possible connections between these skills, it is worthwhile to report data on individual differences in performance. Each participant's mean performance on the tasks were entered along with their standardised test scores into a by participant correlation analysis. The results are reported in Table 2.6.

	Age	BAS	WISC	Def.Nam	Gating	ISR
Age	-					
Reading	.5037**	-				
Vocab	.4501**	.6663***	-			
Def.Nam.	.4638**	.5957***	.7821***	-		
Gating	-.4938**	-.5067**	-.4330**	-.5249**	-	
ISR	.4164**	.5304***	.6452***	.4765**	-.2973	-
Sp. Rate	-.3728*	-.0995	-.2724	-.2258	.1441	-.2802

Levels of significance: *** = p < .001 ** = p < .01 * = p < .05

Table 2.6. By Participant correlation matrix

It is clear from Table 2.6 that a number of significant correlations emerged in this analysis. As expected, a participant's age correlates with their performance on all the measures administered. In addition, reading ability and vocabulary knowledge correlate with each other and with all tasks except Speech Rate. A child's ability to name words to definition significantly correlates with their Serial Recall performance. However, the ISR-Gating correlation was not significant. All these effects may be independent of children's' rehearsal skill, as Speech Rate does not significantly correlate with anything except chronological age.

A series of hierarchical regression analyses were then undertaken, with the aim of identifying the factors that predict unique variance in children's verbal STM ability. This analysis identifies the predictors of recall performance by each participant, averaged across items. The results are displayed in Table 2.7.

	T	r2 change	Sig T
1 Age	2.823	.173	.0075
2 Gating	-.710	.011	.4822
3 DN	2.133	.092	.0398
2 Vocabulary	4.153	.263	.0023
3 Reading	.775	.009	.4436
2 Vocabulary	4.153	.263	.0023
3 DN	-.603	.006	.5503

Table 2.7. Hierarchical linear regression analyses with Serial Recall performance as the dependent variable.

Gating and Definition Naming were entered, to examine how these measures of word recognition and retrieval relate to verbal short-term memory. It was revealed that while the contribution of Gating to memory variance was not independent of age, Definition Naming was a unique predictor. However, conclusions concerning unique predictors in the participants analysis cannot be made without considering vocabulary knowledge, as this correlated highly with Definition Naming and Serial Recall. Therefore, WISC vocabulary knowledge was entered with Definition Naming, and with BAS reading ability. It was observed that the contribution of Definition Naming to Recall variance was accounted for by WISC vocabulary knowledge, as were the links between Recall performance and BAS reading ability. It can therefore be seen that the majority of the links between individual performance levels in ISR and the other tasks are due to the influence of children's' vocabulary knowledge.

2.2.3.5 Analysis of the Relationships between Language Processing Measures and Immediate Serial Recall

As with the other experimental work reported in this thesis, the central focus of the regression analyses was concerned with an items-based approach. Therefore, Lorch and Myers (1990) Method 3 regression was performed, examining the predictors of Serial Recall performance on each item, within each participant. A simultaneous linear regression was carried out, with spoken item length, Definition Naming, Gating, and Speech Rate as the predictors and Recall as the dependent variable. The results are displayed in Table 2.8.

Variable	t	Unique R2	Sig t
Item Length	-.364	.000	.7158
Definition Naming	3.750	.006	.0002
Gating	-1.494	.001	.1355
Speech Rate	.341	.000	.7331

Table 2.8. Within-participant item regression analysis with Serial Recall as the dependent variable

The analysis reveals that Definition Naming does predict unique variance in Recall performance. The greater the likelihood of a participant correctly naming a word in response to it's definition, the more likely they will be to remember that word in ISR. However, neither Speech Rate nor Gating predicts unique variance in Recall in this experiment.

2.2.4 Discussion

This experiment represented a partial replication of the method used in Experiment One, this time examining verbal short-term memory functioning in children. A significant concreteness effect was observed in Immediate Serial Recall, with children correctly recalling more concrete than abstract words. Similarly, facilitatory concreteness effects were observed in Definition Naming and Gating, but not Speech Rate.

An examination of individual differences in task performance revealed a number of significant correlations, most notably between Definition Naming, Vocabulary Knowledge, and Recall. The correlations between Gating, Speech Rate, and Recall were not significant. Regression analyses, with Serial Recall as the dependent variable, revealed vocabulary knowledge to be the only predictor of unique variance in Serial Recall, after controlling for chronological age.

The data from the memory and speech processing tasks were then entered into a Lorch and Myers (1990) regression analysis, with each participant's Recall performance on each item as the DV. With spoken item length also entered, Definition Naming was the only predictor of unique variance in short-term memory performance. Gating, Speech Rate, and item length did not predict significant variance in Immediate Serial Recall.

These results provide a number of interesting insights into verbal short-term memory processing, particularly when set alongside the findings uncovered in Experiment One. Firstly, concreteness effects were observed in Immediate Serial Recall, revealing semantic representations to be influential in children's memory performance (as found by Nation et al., 1999). This suggests that, although less refined than adult performance, developing verbal STM is also reliant on various forms of linguistic coding.

Further examination of the Immediate Serial Recall data does reveal differences between adult and child performance in these experiments. The concreteness effect was influenced by serial position, in that significant concreteness effects only emerged at positions 3, 4, and 5 in the list. This contrasts with previous work that has not observed a significant concreteness x serial position interaction (e.g. Experiment One; Walker & Hulme, 1999; Nation et al., 1999), although it is in line with the effects of frequency reported by Hulme et al. (1997). One possibility is that the temporary phonological representations of children are particularly vulnerable to degradation. This would be exacerbated at later list positions, and so support from semantic processing would become more important.

Immediate Serial Recall error rates also differed between Experiments One and Two. In this second study, concreteness did not influence the rate of order errors per item recalled, with memory performance only varying between item sets because children produced more item errors on abstract words. The pattern of item error subtypes was equivalent to that observed in adults. Children responded with fewer omissions and phonological approximation errors on concrete than abstract word lists. It appears that the lower levels of semantic activation provided by abstract words have reliably deleterious effects on memory for items in children and adults. Interestingly, phonological approximation error rates were inflated for children relative to adults. This is in line with previous reports of such errors in children (Brady, Shankweiler, & Mann, 1983). It may be that the less developed and defined semantic and phonological representations of words possessed by children result in a greater likelihood of selecting and producing a similar but incorrect response.

The argument supported in Experiment One and extended to children's performance by Nation et al. (1999), that concreteness effects in STM reflect underlying language processing, is upheld by the results of this study. The highly significant facilitatory effects observed in Definition

Naming (as in Experiment One) suggest the semantic system to influence Immediate Serial Recall at least partially through the important role the semantics-output phonology pathway may have in both tasks.

In line with the effect found in adults, concreteness also significantly influenced children's Gating performance. As predicted by word recognition models, children were able to identify concrete words on the basis of a smaller initial phonological segment, relative to abstract words. This process of semantic representations acting to support input phonology may be a mechanism common to aspects of the speech input pathway and Serial Recall.

The replication of the null effect on one-syllable word Speech Rate that was found in the previous experiment suggests that concreteness may not significantly impinge on output phonology-articulatory program connections (at least when this processing is relatively straight-forward). These results imply that the effect does not emerge due to any influential role of this aspect of the output pathway in Immediate Serial Recall.

Nevertheless, the significant concreteness advantage observed in the memory task, and the accompanying effects found in measures of speech input and output processing, suggest this effect to emerge in Immediate Serial Recall through the role of the speech processing system. These findings and conclusions are in line with the language-based models discussed in Chapter One (e.g. Monsell, 1984, 1987; R. Martin et al., 1999).

A second source of insight can be gained from examining individual differences in performance, averaging across items. Performance in all memory and language tasks (including the standardised measures) improved with age reflecting the connected development between short-term memory and language processing abilities. Speech Rate did not correlate with Serial Recall, refuting the findings of numerous studies postulating functional and developmental links between these skills (e.g. Baddeley et al., 1975;

Gathercole & Hitch 1993; Hulme et al., 1984; Naveh-Benjamin & Ayres, 1986; Schweickert & Boruff, 1986). The ability to rapidly articulate words (and by extension, the ability to effectively rehearse items) may not be as crucial to verbal memory development as previously thought.

The main finding to emerge from the individual differences analyses was the close relationship between vocabulary knowledge and verbal short-term memory. This supports recent research identifying such links in children, be they causal (e.g. Baddeley et al., 1998) or due to a shared basis within the same system (Gupta & MacWhinney, 1997). For example, Gupta and MacWhinney suggested a non-causal relationship between vocabulary knowledge and immediate verbal memory, with a possible shared basis in the neural areas responsible for speech processing. Vocabulary development involves the setting up and consolidation of lexical semantic and phonological representations within the language system. As short-term memory may crucially depend on temporary activation of these representations, developmental connections between vocabulary and memory are in line with such an account.

Related to this, the correlation and regression analyses revealed Definition Naming performance to be more closely allied than Gating to the development of verbal STM. It is plausible that, while vocabulary knowledge relates equally to representations in input and output phonology and the semantic system, verbal STM as measured by Immediate Serial Recall is comparatively more reliant on the speech output pathway.

The Lorch and Myers (1990) regression replicated the close links between verbal short-term memory and Definition Naming that were found in the previous experiment. Again, the probability of a participant producing a word to its definition predicted their success in recalling that word. This would suggest the output pathway, and in particular semantics to output phonology connections and access to phonological representations, to be important in Immediate Serial Recall. In turn, the concreteness effects observed in memory would then be attributable primarily to output functioning. Speech Rate did not predict unique variance in short-term memory (in contrast to Experiment One), nor did Gating, thus indicating the precise mechanisms underlying these tasks to be relatively less influential in Serial Recall.

2.3 Experiment Three: Concreteness in 'On-line' Language Processing and Verbal Short-Term Memory

2.3.1 Introduction

The findings obtained in the first two experiments were interpreted as evidence for a link between short-term memory and speech processing, particularly speech production. However, the nature of the speech processing measures in Experiments One and Two mean that further empirical work was required in order to build a theoretical case.

As the primary measure of production, the Definition Naming procedure used in the first two experiments can be said to be comparatively 'off-line'. Participants had time to consider the definitions, and use various strategies to produce a response. In addition, the heavy semantic load of this task means that the probability of obtaining a semantic variable effect would be high. This point is not a criticism of the task, as phonological retrieval from semantic activation is what Definition Naming is designed to measure. Further insight into short-term memory and output processing would be obtained from the use of a more 'on-line', phonological task. Although Speech Rate could be said to provide such a measure, this has often been used as an indirect gauge of rehearsal speed.

It is also useful to examine input processing, using measures other than Gating. There are problems associated with this word recognition task that may have confounded any influence of semantic effects, and resulted in the failure to predict short-term memory performance. For example, the repeated presentation of stimuli that leads to eventual recognition in Gating may induce response perseveration, thus yielding a conservative picture of recognition (Craig & Kim, 1990; Walley, Michela, & Wood, 1995). Furthermore, this task has previously been labelled as off-line, reflecting post-access operations. Although Grosjean (1996) has argued against such criticisms, it was deemed useful to examine performance in a comparatively on-line measure of recognition.

The two new tasks used in this experiment were Immediate and Delayed Repetition (output) and Auditory Lexical Decision (input). These measures are assumed to be relatively on-line, and both feature reaction time as the dependent variable. Tyler et al. (2000) reported more reliable effects of imageability (a variable closely related to concreteness) in Lexical Decision than Repetition. If concreteness effects typically emerge in short-term memory as a result of input processing, equivalent effects would be predicted in the present experiment in both Lexical Decision and recall performance. In addition, this measure of input would possibly predict variance in recall in a way that Gating failed to, due to it potentially tapping different aspects of speech perception.

Delayed Repetition can be viewed as a measure of articulation speed on the basis of phonological output processing, from initial auditory input. Thus, it taps very different aspects of production from those measured in Definition Naming. Due to the phonological nature of the task, smaller concreteness effects would be predicted than those obtained in the previous experiments. Strain et al. (1995) suggested that word meaning only influences Visual Naming performance (a task that is similar to Repetition) on irregular and low-frequency words. In line with this, de Groot (1989) only observed a very small effect of imageability on naming. As the items that were used in this experiment were generally regular and of mid-range frequency, it was of interest how and if concreteness would influence Repetition. Any effect of word meaning on this phonological repetition task may provide support for an interactive bi-directional model of speech production (e.g. Dell, 1986; Dell et al., 1997). Also of importance was the relation of this task to recall performance. If ease of Delayed Repetition would significantly predict short-term memory (as Definition Naming did), this would suggest processes throughout the speech output system to be critical to temporary memory recall.

Also of potential interest was a comparison between Immediate and Delayed Repetition. The delays used in this experiment were generally assumed to be long enough to rule out any substantial effects of input processing. The phonological information would have been comfortably processed, and activation conveyed to the production system. In contrast, Immediate Repetition may tap ongoing perceptual processes and interaction between input and output phonology, as well as speed of production.

The aim of this experiment was to find if the pattern of results obtained in the previous experiments using comparatively 'off-line' tasks could be replicated using more on-line measures of speech processing. These measures were employed to examine how different aspects of speech perception and production were a). influenced by word meaning, and b). related to Immediate Serial Recall.

The semantic factor manipulated in this experiment was again rated concreteness. In contrast to the previous adult experiment, all items were one syllable in length, and were controlled for number of phonemes. To accomplish this, a new set of items was selected. As in the previous studies, the repeated measures design enabled an examination of how a participant's performance on an individual item in the language tasks predicted recall of that word.

2.3.2 Method

2.3.2.1 Participants

Twenty-two undergraduate and postgraduate students (10 males, 12 females) from the University of York took part in this experiment. Participants received monetary payment or course credit for taking part.

2.3.2.2 Materials

Two sets of twenty-six words were used in this experiment, manipulated according to rated concreteness (concrete or abstract). The sets were matched for rated age of acquisition, rated frequency, Kucera-Francis (1967) frequency, familiarity, length, number of phonemes, and related senses.

Concreteness, age of acquisition, and frequency ratings were obtained by distributing rating booklets to postgraduate and undergraduate students, researchers, and faculty members at the University of York Psychology department. Each 7-page booklet contained 120 one-syllable words of moderate frequency, originally drawn from the MRC Psycholinguistic database. Instructions were presented on the initial sheet concerning how to rate the items based on their concreteness, frequency, or age of acquisition. Concreteness and frequency were rated on a seven-point scale, and age of acquisition on a nine-point scale. Forty-five people rated the items on one variable each, producing 15 individual ratings of the words on each variable.

From these ratings the matched sets of concrete and abstract words were selected. Full details of the stimuli can be found in Appendix D. The final item sets were tested with a series of one-way analyses of variance, in which stimulus group was the independent variable and each word factor the dependent variables. These ANOVAs confirmed that the only significant difference was in concreteness (F (1,51) = 646.67, $p < .001$).

Practice items for Lexical Decision and Repetition were then selected from the remainder of the initial 120 word set. In addition, wordlike nonwords were created for the Lexical Decision segment of the experiment, by taking real words of moderate frequency and altering one phoneme in each word. The nonwords had a similar distribution of word lengths to the test stimuli.

All stimuli were recorded by a female English speaker onto a Sony minidisk recorder in a soundproofed room. They were then transferred onto a Macintosh computer using Soundedit 16. As Lexical Decision was administered using a PC, the items were also copied and formatted onto that machine, using the Goldwave sound-editing program.

2.3.2.3 Procedure

Each participant performed each task, with the same 52 items featured in each. The four tasks were administered in a single, one-hour session, in the same order for each participant. To minimise priming problems, Auditory Lexical Decision was performed first, then Repetition (Immediate and Delayed), followed by Immediate Serial Recall, and finally Speech Rate.

Auditory Lexical Decision (ALD) Testing was controlled by a PC, using the DMDX program. Participants were played the test words and non-words through headphones, with their task being to decide as quickly as possible (via a button box) whether each item was a real word or not. Twenty practice items preceded the test phase, which consisted of 52 words and 52 nonwords presented to the participant in random order.

Repetition (REP) Presentation was controlled using the Macintosh based PsyScope program. Each trial commenced with a 1000 ms 'O' fixation point in the centre of the screen, to prepare the participant. After a subsequent 500 ms delay, a single item was presented through the speaker. Following a further delay of 5ms, 1000ms, or 3000 ms, an 'X' cue was presented on the screen. This remained in view until a response was made. Each word was presented three times (once after each delay), in random order, resulting in a total of 18 practice items and 156 test items. In this way, measurements of immediate (5ms delay) and delayed (1000ms and 3000ms) repetition were obtained.

The participant was asked to listen to each word, and repeat it as soon as they saw the 'X' cue. They were informed of a variation in delay duration between word and cue presentation, although no details of the length of delays were given.

Immediate Serial Recall (ISR) Testing was performed with a Macintosh computer, using the same digitised stimuli featured in the Lexical Decision and Repetition tasks. Each of the two word sets (Concrete and Abstract) were presented in their own 26 list series, with seven items in each list. The same presentation procedures and pseudo-randomisation constraints used in the previous experiments were used again.

Speech Rate (SR) Finally, the rate at which participants could repeatedly articulate each word was recorded, using the procedure described in previous chapters.

2.3.3 Results

2.3.3.1 Summary of Task Performance

	Concrete	Abstract
Serial Recall (%)	63.29 (sd=13.63)	59.24 (sd=15.18)
ALDT (ms)*	297.11 (88.27)	299.15 (83.25)
Repetition		
Immediate (ms)	447.44 (21.14)	450.05 (20.65)
1 sec delay	394.25 (18.16)	399.22 (16.12)
3 sec delay	372.60 (15.69)	379.06 (19.59)
Delayed Repetition (mean of 1 + 3)	383.42 (14)	389.14 (16.17)
Speech Rate (words/sec)	3.37 (.26)	3.28 (.18)

Table 2.9. Means (and standard deviations) for performance on the speech and memory tasks, on each word set.

*ALDT refers to Auditory Lexical Decision Time. As the length of the spoken sound-files were not controlled across the item sets, a potential confound exists. To overcome this, item length (in milliseconds) was subtracted from each participant's reaction time for that item. This yields a measure of decision time, in relation to item offset. For example, an ALDT of 300 ms signifies a response made 300 ms after item offset.

It can be seen in Table 2.9 that concreteness has different effects on performance in the four tasks. No observable advantage for concrete over abstract words is apparent in the input measure (Lexical Decision). Conversely, participants were able to recall more concrete than abstract words in the STM task, although this difference was smaller than that observed in Experiment One. A very small but consistent concreteness effect was found in Repetition, at each of the delays and overall. It is also apparent that reaction time decreases with increasing delay between stimuli presentation and production cue. Finally, there appears to be a concreteness effect on Speech Rate, in that participants were able to articulate concrete words faster than abstract words.

2.3.3.2 Immediate Serial Recall

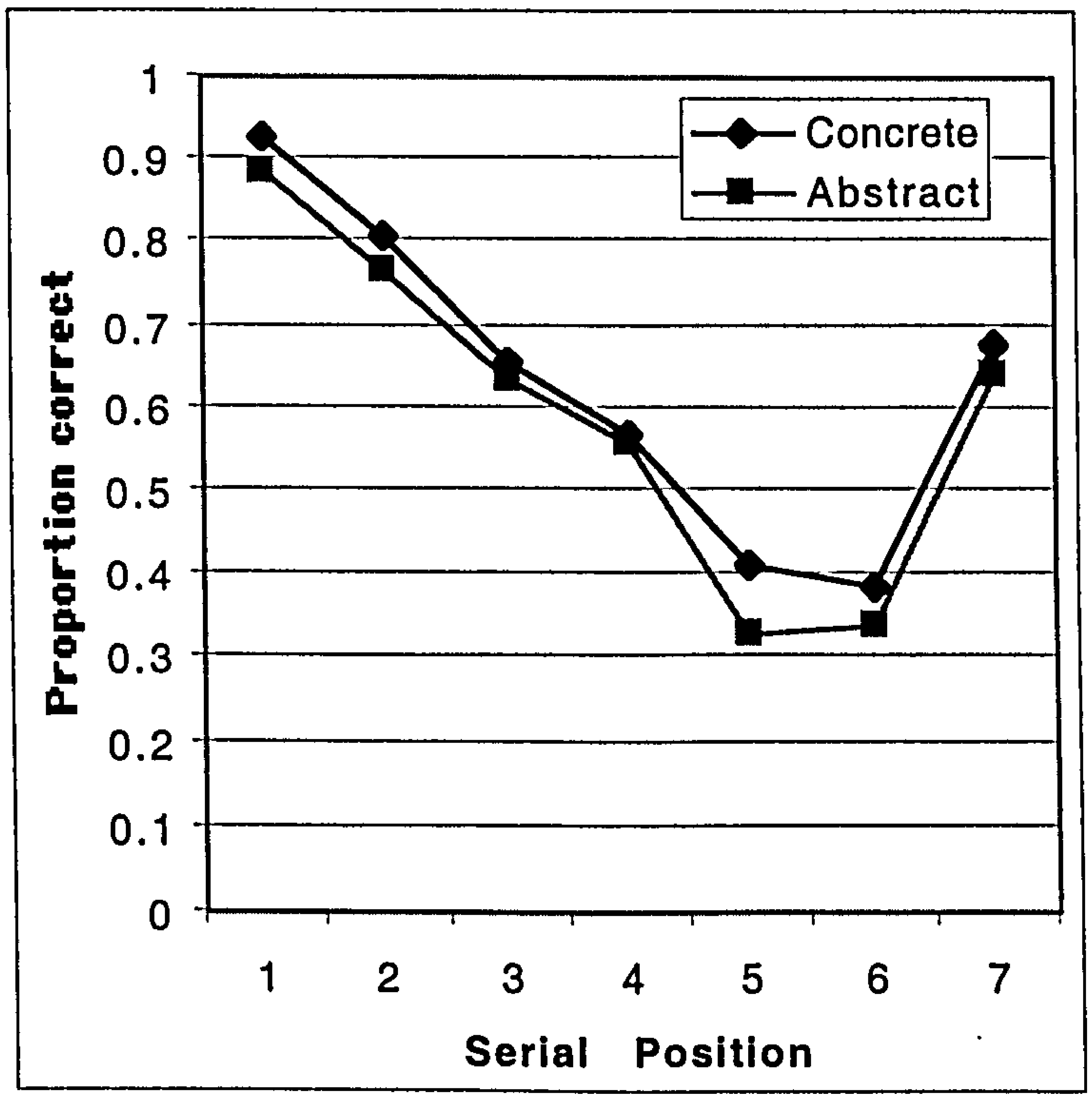


Figure 2.3. Recall as a function of concreteness and serial position.

The Serial Recall data were plotted as a function of proportion correct at each serial position (Figure 2.4). A bowed serial position curve is apparent for both concrete and abstract words, with a large primacy effect and a smaller recency effect. Differences in performance between concrete and abstract words are apparent at the majority of serial positions (excluding positions 3 and 4), and are particularly pronounced at the fifth list position.

The recall data were entered into a two -way repeated measures ANOVA, with concreteness and serial position as the factors. This produced significant effects of concreteness ($\underline{F}$ (1,21) = 6.56, $\underline{p} < .05$) and serial position

(F (6,126) = 62.97, p < .001). There was no significant concreteness x position interaction (F (6,126) = .62, p = .715).

In order to reveal more about the influence of concreteness on Immediate Serial Recall, an examination of response types in this task was undertaken. Responses were initially classed as correct or incorrect, with incorrect responses being divided into order and item errors. A further distinction was made in the types of item error, with such responses being categorised as omissions, intra-set intrusions, intra-experiment intrusions, extra-experiment intrusions, or phonological approximation errors. The results of this analysis can be seen in Table 2.10.

		Errors						
			Item Errors					
Word set	Correct	Order	Total Item	Omissions	ISI	IEI	EEI	PA
C	.633	.115	.252	.206	.036	.001	.001	.010
A	.592	.124	.283	.234	.028	.000	.001	.019

Table 2.10. Response patterns in Serial Recall for each word set

The pattern of errors across the two item sets was examined in a series of t-tests. The rate of conditionalised order errors (errors per item correctly recalled) was .159 for concrete word lists, and .181 for lists of abstract words, a difference that was not significant (t (21) = 1.67, p = .110).

The concreteness effect on overall item-based errors was significant (t (21) = 2.46, p < .05), as was the effect on omission errors (t (21) = 2.32, p < .05). Similarly, there was a significant effect of concreteness on phonological approximation errors (t (21) = 3.27, $p < .01$). However, the concreteness effect on intra-set intrusion errors was not significant (t (21) = -1.90, p = .071). Intra-experiment and extra-experiment intrusion errors were extremely low in occurrence, so were not examined further.

To summarise, concreteness does have a significant positive effect on Immediate Serial Recall performance. This effect appears to arise in this experiment through an increased rate of item-based errors, specifically omission errors and phonological approximation errors, on abstract words.

2.3.3.3 Analysis of Performance on the Language Tasks

Auditory Lexical Decision

The Auditory Lexical Decision reaction times, as measured from item offset, did not differ across participants (t (21) = .30, p = .771) or across items (t (50) = .05, p = .962).

Error rates in Lexical Decision were typically low, with 6.73% of all responses being incorrect. There were slightly more errors made on concrete (7.87%) than abstract (5.59%) words. This difference was not significant by-participants (t (21) = -1.77, p = .091) or by-items (t (50) = 1.02, p = .315).

Immediate and Delayed Repetition

Immediate Repetition (5ms delay) reaction times did not differ across participants (t (21) = .27, p = .790) or across items (t (50) = .45, p = .654).

Delayed Repetition (1000ms and 3000ms) data were then examined. A 2x2 repeated measures ANOVA with concreteness and delay length as the factors revealed a significant effect of delay (F (1,21) = 24.46, $p < .001$).

However, the effect of concreteness was not significant (F (1,21) = 3.38, p = .080), nor was the concreteness x delay interaction (F (1,21) = .21, p = .649).

A by-item ANOVA also revealed a significant effect of delay (F (1,103) = 37.26, p < .001), while the concreteness effect was not significant (F (1,103) = 2.79, p = .098). The concreteness x delay interaction was not significant (F (1,103) = .047, p = .828).

Speech Rate

A two-tailed paired t-test was performed on the Speech Rate participant means. This revealed a significant effect of concreteness on performance (t (21) = -2.10, p < .05). However, the concreteness effect was not significant in the items-based analysis (t (50) = .86, p = .393).

To summarise these analyses, concreteness was shown to have a significant effect on Immediate Serial Recall performance. This effect was independent of the influence of serial position, and was limited to the recall of item information. Concreteness also had a marginal but significant effect on Speech Rate, in the participants analysis at least. However, it did not significantly influence Repetition or Auditory Lexical Decision performance.

2.3.3.3 Analysis of the Relationships between Language Processing Measures and Immediate Serial Recall

A Lorch and Myers (1990) Method 3 regression analysis was performed, examining the predictors of recall performance on each item, within each participant. A simultaneous linear regression was carried out, with voiced item length, Auditory Lexical Decision, Immediate Repetition, and Speech Rate as the predictors and Recall as the dependent variable. The results are displayed in Table 2.11.

	t	Unique R_2	Sig t
Item Length	-.950	.001	.3425
Auditory Lexical Decision	-.701	.000	.4836
Immediate Repetition	-1.106	.001	.2690
Speech Rate	1.031	.001	.3028

Table 2.11. Within-participant item regression analysis with Serial Recall as the dependent variable

It can be seen from Table 2.11 that, in this experiment, none of the predictors account for unique variance in Immediate Serial Recall performance. A similar analysis was then performed, using Delayed Repetition (each participant's mean response times after 1 and 3 second delays) instead of Immediate Repetition as a predictor. The results are displayed in Table 2.12.

Variable	t	Unique R_2	Sig t
Item Length	-.865	.000	.3875
Lexical Decision	-.815	.000	.4155
Delayed Repetition	-.543	.000	.5869
Speech Rate	.785	.000	.4328

Table 2.12. Within-participant item regression analysis with Serial Recall as the dependent variable

Again, there were no significant predictors of unique variance in Serial Recall in this analysis.

2.3.4 Discussion

Significant concreteness effects were again observed in Immediate Serial Recall, although the difference in performance between item sets was relatively small at around 4%. In contrast, concreteness did not significantly influence Auditory Lexical Decision performance, in terms of reaction time or error rates. A small trend towards a concreteness effect was apparent in the Immediate and Delayed Repetition response times, although this was non-significant. A significant concreteness effect was observed (in the participants analysis) in the Speech Rate task. Finally, regression analyses revealed that unique variance in Immediate Serial Recall was not predicted by any of the three speech processing tasks in this experiment.

Concreteness does have a reliable effect on Immediate Serial Recall performance, replicating previous findings in Experiments One and Two, and Walker and Hulme (1999). This effect appears to impinge on memory for and retrieval of item information. An error analysis revealed significant concreteness effects on item but not order error rates. Specifically, more omissions and phonological approximations were made when recalling lists of abstract words than on lists of concrete words. This is in line with the item error rates observed in previous experiments. It appears that words in a list are coded in terms of their meaning as well as their phonology (as suggested by R. Martin et al., 1999), with this temporary semantic activation possibly serving to support phonological processing. This semantic support for phonology approach is upheld by the observation of increased PA error rates for abstract words. The concreteness effect is not limited to certain positions in the list, as the word set x serial position interaction was not significant, replicating previous work (e.g. Experiment One; Walker & Hulme, 1999).

The finding that concreteness did not influence reaction times in Auditory Lexical Decision contrasts with previous research, where this variable did significantly affect Gating performance. This also contrasts with

Lexical Decision research, which has reported significant beneficial effects of word concreteness and imageability (e.g. Tyler et al., 2000). In the present experiment, spoken item length was not equivalent between the two item sets. This would have a substantial influence on ALD performance, as longer words take longer to recognise and respond to, regardless of their meaning. To control for this confound, decision time from item offset was used as the measure of performance. It may be that concreteness and imageability effects reported in Auditory Lexical Decision research were the result of variations in uncontrolled spoken item length.

Auditory Lexical Decision is a very different input task to Gating. As noted by Plaut (1997), participants will base lexical status judgements on any available information, and will rely on phonology alone when this will suffice. They did not require the extra semantic support provided by concrete words to successfully process the test items in this experiment. These results suggest that participants do not necessarily utilise available semantic information when performing all input tasks. In turn, it can be inferred that concreteness effects in verbal short-term memory tasks do not primarily emerge through the influence and involvement of speech input processing.

Moving on to the Repetition task, it was observed that reaction times were faster when delays between auditory input and response cue were longer. It may be that in Immediate Repetition (and to a lesser extent 1 sec delay Repetition), the stimuli input are still being actively processed, and defined activation has not been fully conveyed via output phonology to allow selection and preparation of motor programs.

Although there was a consistent trend towards a beneficial concreteness effect in trials involving every delay length, this was very small and not significant. The effect size was equivalent in magnitude to that observed by de Groot (1989) in visual naming. When repeating a word, activation can be conveyed from input phonology to semantic representations and from there to output phonology and articulatory programs. Use of this route only would result in large concreteness effects in repetition tasks, as observed by Newton and Barry (1997). However, although this route would be activated in word repetition due to the nature of the system, it would not necessarily be required as repetition can also be performed using a second pathway, via non-semantic input-output phonology connections. It is likely that both these routes would become active in repetition, but that the non-semantic phonology pathway would generally be efficient enough to accomplish the task, without the influence of semantic processing (as suggested by Strain et al., 1995), hence the lack of significant effects.

A significant advantage for concrete over abstract words was observed in Speech Rate performance. This contrasts with the null results obtained on one-syllable words in the previous two experiments. As with Repetition, Speech Rate can be performed without any support from semantics, as the task can be accomplished using solely phonological processing. Concreteness effects may emerge in Speech Rate (and to an extent in Immediate Serial Recall) through semantic support ensuring that representations in output phonology and the articulatory program remain active and well defined. The emergence of such influences on one-syllable items in this experiment may be due to power issues. In Experiments One and Two, each one-syllable word set consisted of 16 items, while the present experiment featured two sets of 26 words. As semantic processing may only have a relatively small influence on Speech Rate, the likelihood of detecting such small effects would increase with a larger item set.

Concreteness effects in Speech Rate are better predicted by cascade models of production (e.g. Dell, 1986; Dell et al., 1997), which describe activation spreading through the system from semantics to output phonology and articulatory processing. The serial nature of models such as WEAVER++ (e.g. Levelt et al., 1999), in which activation does not freely feed forward and back, does not account for these findings so easily. However, the size of concreteness effects in Speech Rate, and the lack of a significant effect in Immediate or Delayed Repetition indicate a restrained interactive model of memory (e.g. Dell et al., 1997) to be more appropriate.

Overall, evidence was found to indicate that the participants made use of semantic information to improve performance in verbal STM and, to a lesser extent, in a speech production task (thus providing some support for language-based models of short-term memory). However, significant concreteness effects did not emerge in Repetition, a task in which participants were able to process phonological information without the need for support from semantic processing. Furthermore, their performance in a word recognition task (Lexical Decision) did not show an influence of semantic processing. This would suggest that the concreteness effect in Serial Recall emerges through semantic support for phonological processing in the speech output pathway. It would be unwise however to attempt to draw strong conclusions from these findings, as many of them involve marginal or null effects.

As noted, there were no significant predictors of a participant's Serial Recall of each word in the Lorch and Myers (1990) regression analyses. As with Gating in the previous experiments, Auditory Lexical Decision performance was not related to verbal short-term memory. Similarly, using a different measure of speech production to that featured in Experiments One and Two, neither Immediate nor Delayed Repetition predicted recall. The same was true for Speech Rate.

At first glance, this pattern of null results would appear to suggest few aspects of speech processing to be involved in Immediate Serial Recall, refuting language-based models of memory (e.g. Monsell, 1984, 1987). However, these results do not preclude such an explanation of verbal STM. When hearing a word list, temporarily storing it in terms of various linguistic factors, and retrieving it as a response, the participant will necessarily utilise input phonology, semantic representations, output phonology, articulatory programs, and the connections between these capacities, in short, the general mechanisms involved in the tasks presently discussed. Instead, the regression analyses indicate that the precise operational mechanisms tapped by Lexical Decision, Repetition, and Speech Rate may not be absolutely central to Immediate Serial Recall performance.

2.4 Chapter Summary

The first experiment reported in this chapter replicated previous findings concerning word length (e.g. Baddeley et al., 1975) and concreteness (Walker & Hulme, 1999) in adult short-term memory performance. In addition, concreteness and length effects were also observed in two different measures of speech production processing, and a measure of word recognition. Finally, the recall of a word was significantly predicted by output but not input performance.

These findings were then extended to children's performance in a second experiment using a very similar procedure, although without the manipulation of word length. The concreteness effect was observed in Immediate Serial Recall, suggesting that children also make use of multiple forms of linguistic coding in this task (Nation et al., 1999). In line with this, concreteness also influenced performance in measures of word recognition and speech production. An examination of individual differences in performance revealed strong links between STM and vocabulary knowledge, possibly reflecting their shared basis in language processing (Gupta & MacWhinney, 1997), particularly output mechanisms. A regression analysis again revealed recall to be predicted by output but not input processing.

The relationships between various aspects of the speech processing system and verbal short-term memory, and the effects of concreteness on these cognitive processes, were then examined with the use of two different language measures, Auditory Lexical Decision and variable delay Repetition. Concreteness was found to again significantly facilitate item memory in Immediate Serial Recall, with more omissions and phonological errors made on abstract word lists. Small but significant concreteness effects were also observed in Speech Rate, although the trend towards an effect in Repetition was not significant. In contrast, concreteness did not significantly influence Lexical Decision reaction times. Finally, regression analyses revealed that none of the speech processing tasks predicted unique variance in Immediate Serial Recall performance.

The results suggest that verbal information is temporarily stored in terms of multiple linguistic coding, including phonology and word meaning. In addition, semantic processing appears to influence various aspects of the speech production pathway, although this influence may wane the 'further down the output path' the critical processing takes place, and the less demand that is placed on semantic support. In contrast, word recognition performance does not necessarily benefit from this particular semantic variable, with significant effects on Gating but not Lexical Decision. From this, it may be inferred that the concreteness effect in Serial Recall may primarily emerge through processing within the speech output pathway, particularly through the interaction between the conceptual system and output phonology.

These findings are indicative of a verbal short-term memory system that is reliant on speech processing representations and mechanisms. It may be that items are coded in terms of meaning and sound, and that these representations normally operate in perceiving and producing speech. Specifically, the pattern of results suggest that the temporary storage and retrieval of semantic and phonological information may be primarily based on representations serving the speech output pathway.

However, the finding that none of the tasks in Experiment Three predicted memory performance would indicate that the precise mechanisms underlying successful lexical status judgements, rapid onset of articulation, or rapid repeated articulation, although possibly still involved in Immediate Serial Recall, were not central to participants' performance in this task. The caveat particularly connected to this experiment, however, is that many of the conclusions were drawn from marginal or null effects.

Chapter Three

Semantic Ambiguity Effects in Word Recognition and Verbal Short-Term Memory

In the previous chapter, a semantic variable (concreteness) had significant effects on verbal short-term memory performance, in adults and children. This was interpreted as reflecting an important role for language processing mechanisms in the temporary storage and retrieval of verbal information. It may be that representational capacities within the speech processing system are responsible for holding and retrieving different levels of linguistic information in verbal short-term memory tasks. Concreteness effects would then emerge through the storage of information within the semantic system, and the influence of this semantic activation on the wider speech processing system. This was supported by the observation of concreteness effects in language processing measures, particularly production tasks.

The results discussed so far suggest output processing (speech production) to be relatively more critical to short-term memory performance than input processing (speech perception). The pattern of concreteness effects in production tasks provided insight into how semantic processing influences speech production, and how such effects may also arise in Serial Recall. Although concreteness may also influence short-term memory through interactions between input phonology and semantics, the effect of this variable on word recognition was relatively small and limited to a single task. Importantly, regression analyses revealed that a participant's memory recall and speech production probability for each word were linked. In contrast, input task performance was unrelated to short-term memory in these analyses.

Nevertheless, all aspects of speech processing should be involved to some degree in aurally presented Immediate Serial Recall tasks. It was therefore important to examine more closely how the input pathway may be involved in verbal short-term memory. The use of a single measure of speech input in the three experiments reported so far may not have provided a full insight into perception processing and its possible relationship with verbal memory. To this end, two different speech input tasks were administered. In addition, while concreteness may be a variable influencing Serial Recall primarily through production processing, other effects might arise in verbal memory as a result of perceptual mechanisms. Therefore, the influence of a semantic variable that is known to influence word recognition (ambiguity) was assessed. It was predicted that semantic ambiguity effects would emerge in the measures of word recognition. Related to this, if the input pathway does have an important role in the temporary storage and retrieval of verbal information as some have suggested (e.g. Burgess & Hitch, 1999; Gathercole

& Martin, 1996; Monsell, 1984, 1987), similar ambiguity effects would be expected in Serial Recall.

3 Semantic Ambiguity Effects in Speech Input Measures and Immediate Serial Recall

3.1 Introduction

Semantic ambiguity is generally studied using different words that share the same orthography and/or phonology. Specifically, homographs are defined as sharing orthography (e.g. *live),* homophones share phonology (e.g. *wood-would*), while homonyms share both (e.g. *bark*). It was the latter form of ambiguity that was examined in this experiment. Ambiguity is a useful variable to examine because, not only is it a subtle semantic manipulation (relative to concreteness), it has been shown to have a significant influence on the processes of word recognition.

Previous research has in the majority focused on ambiguity effects in visual recognition tasks, with many studies reporting a processing advantage for ambiguous over unambiguous words (e.g. Azuma & Van Orden, 1997; Borowsky & Masson, 1996; Hino & Lupker, 1996; Kellas, Ferraro, & Simpson, 1988; Millis & Button, 1989). However, Rodd et al. (2002) identified problems with the stimulus sets used in many of these studies. They found that the ambiguous word sets often included words that were not truly ambiguous, or had clusters of highly related senses (different interpretations of the same central meaning, all classified under a single dictionary entry). Therefore, any apparent advantages of ambiguity in these studies may instead reflect a beneficial effect of related senses on word processing.

Using new word sets divided on the basis of ambiguity and related senses, Rodd et al. (2000, 2002) observed facilitatory effects of related senses and inhibitory effects of ambiguity in visual and auditory lexical decision tasks. It appears that the semantic profile of a word does influence recognition, in that a word with several unrelated meanings will be processed less efficiently than one with a single meaning. In contrast, a word associated with a number of highly related senses, clustered around a single central meaning, will be processed more efficiently than a word with few related senses.

Recent connectionist models of word recognition (e.g. Gaskell & Marslen-Wilson, 1997; Hinton & Shallice, 1991; Plaut & Shallice, 1993) attribute inhibitory ambiguity effects to semantic competition. At the semantic level, a word must win the competition for activation of semantic representations to be recognised. When processing ambiguous words, two or more different and unrelated semantic patterns will be partially activated in response to a single visual or auditory input, and thus interfere with each other. Rodd et al (2002) claimed that this competition would increase the time taken for a stable activation to be produced and consequently would slow recognition.

Therefore, an adverse effect of homonym ambiguity would be predicted in any task measuring the processing of orthographic or auditory input, providing that the task is sufficiently sensitive. The first of these tasks was Auditory Lexical Decision. In contrast to previous research, significant concreteness effects did not emerge in this measure in Experiment Three. This does not necessarily indicate word recognition to occur without recourse to semantic information. Participants were merely able to respond to the stimuli without a significant influence of word concreteness. In contrast, Rodd et al. (2000, 2002) did report inhibitory ambiguity effects in Lexical Decision, and a potential replication of these findings (using the Rodd et al. stimuli) was the initial focus of this experiment.

In order to examine whether the ambiguity effect is sufficiently robust to extend to other measures, Word Identification in Noise was used as a second speech input task. This task measures the signal-to-noise ratio in which items are correctly identified, with ease of processing reflected by correct identification in higher levels of noise. Participants must compare degraded auditory input with representations in input phonology, and produce a response on the basis of the best fit. Word Identification in noise is said to have strong face validity (Hawley, 1977), with variables such as word frequency, length, and neighbourhood influencing performance (e.g. Egan, 1948; Luce et al., 1990; Owens, 1961). It provides a relatively 'off-line' measure, similar in some respects to Gating (in the repeated presentation of items, gradually improving in salience). In contrast to Lexical Decision, Word Identification in noise is not timed, and requires item identification rather than mere recognition. Nevertheless, connectionist theory would predict significant inhibitory ambiguity effects.

As with previous experiments, Immediate Serial Recall was used as the measure of verbal short-term memory. This represents the first time that semantic ambiguity has been manipulated in such a paradigm. The inhibitory semantic ambiguity effect may be viewed as a variable limited to input only. Ambiguity is only assumed to have adverse effects on linguistic processing when, at the crucial point of the task, semantic competition occurs in response to phonological input processing. In contrast, the ambiguity effect may not adversely affect processing in the output pathway. Therefore, if the input pathway is critical to verbal short-term memory, ambiguity should inhibit performance in both recognition tasks and in Immediate Serial Recall, through interaction between input phonology and semantic representations. However, if speech input mechanisms are not the primary storage capacities involved in Serial Recall, marginal or no ambiguity effects (relative to concreteness) would be predicted.

Finally, Speech Rate was included as a basic measure of production processes. As noted, concreteness has been shown to have a small yet significant effect on Speech Rate (in Experiments One and Three). However, it may be that semantic ambiguity would not inhibit performance in this task, due to its potential nature as an 'input-only' inhibitory effect.

3.3 Method

3.3.1 Participants

Twenty-six University of York undergraduate and graduate students took part, receiving payment or participant credit for their participation. The sample consisted of 1 male and 25 females, with an age range of 18-26 years.

3.3.2 Materials

The item set consisted of 46 words (23 ambiguous and 23 unambiguous), taken from Rodd et al. (2000, Experiment 2). Words were classed as to their ambiguity on the basis of the number of entries in The Online Wordsmyth English Dictionary-Thesaurus (Parks et al., 1998), with unambiguous words having one entry and ambiguous words having two or more. The two groups were matched on frequency, familiarity, mean concreteness, number of related senses, number of phonemes, uniqueness point, number of syllables, and spoken item length (ms). The full word lists are provided in Appendix E.

All digital sound-files used in the experiment were taken from Rodd et al. (2000), in an effort to replicate and extend the findings of their study. This included target items, practice items, and nonwords (for the Lexical Decision segment of the experiment).

For the Word Identification in Noise task, the sound-files for the 46 words were equalised for overall energy level at 65 dB, in an attempt to ensure equivalent masking. They were then embedded in 1200 ms of white noise at eight varying signal-to-noise ratios ranging from -13 to 0 dB, and presented in a pilot study to establish the four signal-to-noise ratios with the most suitable identification distribution patterns for the 46 items.

3.3.3 Procedure

A similar design to the previous experiments was used, in that participants were tested individually on all the tasks, with the same 46 items featuring in each. The four tasks were administered in the same order to each participant, in a one-hour session.

Auditory Lexical Decision (ALD) Testing was performed using the procedure outlined in Experiment Three. Thirty practice items preceded the test phase, which consisted of 46 words and 46 non-words presented randomly for each participant.

Word Identification in Noise (WIN) Preparation and testing was controlled on a PC, with stimulus presentation performed using DMDX. Participants were given four-page response booklets, labelled Rounds 1-4. Each sheet contained a table marked 1-46 with a corresponding space for each response. In Round One, the 46 items were embedded within 1200ms of white noise, using a –13 dB signal-to-noise ratio. Participants heard each item through headphones, and were asked to identify them on the response sheet. The trials were self-paced, with participants pressing a key to move on to the next item. The items were then presented in Round Two with a –8 dB signal-to-noise ratio (in which the noise level is lower), with participants again recording their responses. This continued for Round Three (-6 dB signal-to-noise ratio) and Round Four (-1 dB signal-to-noise ratio). The order of items was randomised within each round for each participant.

Participants were told that each round contained the same items, and to continue responding even if they had already identified each item in the previous round. They were not informed of any connection with the previous task, and no feedback was given at any point.

Immediate Serial Recall (ISR) Testing was performed using the same digitised stimuli featured in the Lexical Decision and Word Identification in Noise tasks. Each of the two word sets (Ambiguous and Unambiguous) were presented in their own 23 list series, with seven items in each list. The presentation procedure and pseudo-randomisation constraints used in the previous experiments were again implemented, so that each word was presented once in each serial position.

Speech Rate (SR) Finally, the rate at which participants could articulate each word was recorded. Test items were presented one at a time, with participants being asked to repeat each one 10 times as quickly and accurately as possible. The time for each item was recorded using a stopwatch.

3.3 Results

3.3.1 Summary of Task Performance

	Ambiguous	Unambiguous
ISR (%)	53.01 (12.33)	56.12 (11.85)
ALDT (msecs)	365.33 (99.80)	335.17 101.18)
WIN (mean round ID)*	2.91 (.29)	2.67 (.30)
Speech Rate (w/s)	3.15 (.60)	3.14 (.59)

*The WIN mean round ID score refers to the mean round (1-4) at which words were correctly identified. If a word was not identified, a score of 5 was given.

Table 3.1. Means (and standard deviations) for the language and memory measures, on each word set

It can be seen from Table 3.1 that both the Lexical Decision and Word Identification in Noise tasks show inhibitory effects of ambiguity. Unambiguous words appear to be processed more quickly, and are easier to identify when embedded in noise. In addition, a small advantage is apparent for unambiguous over ambiguous words in Serial Recall. Finally, there appears to be no difference in Speech Rate between the two word sets.

3.3.2 Immediate Serial Recall

The Serial Recall data were plotted as a function of proportion correct at each serial position (see Figure 3.1). A bowed serial position curve is apparent for both ambiguous and unambiguous word sets, with large primacy and recency effects evident. Although performance on unambiguous words shows an advantage in serial positions 2 and 3, there does not appear to be any consistent substantial differences between the word sets.

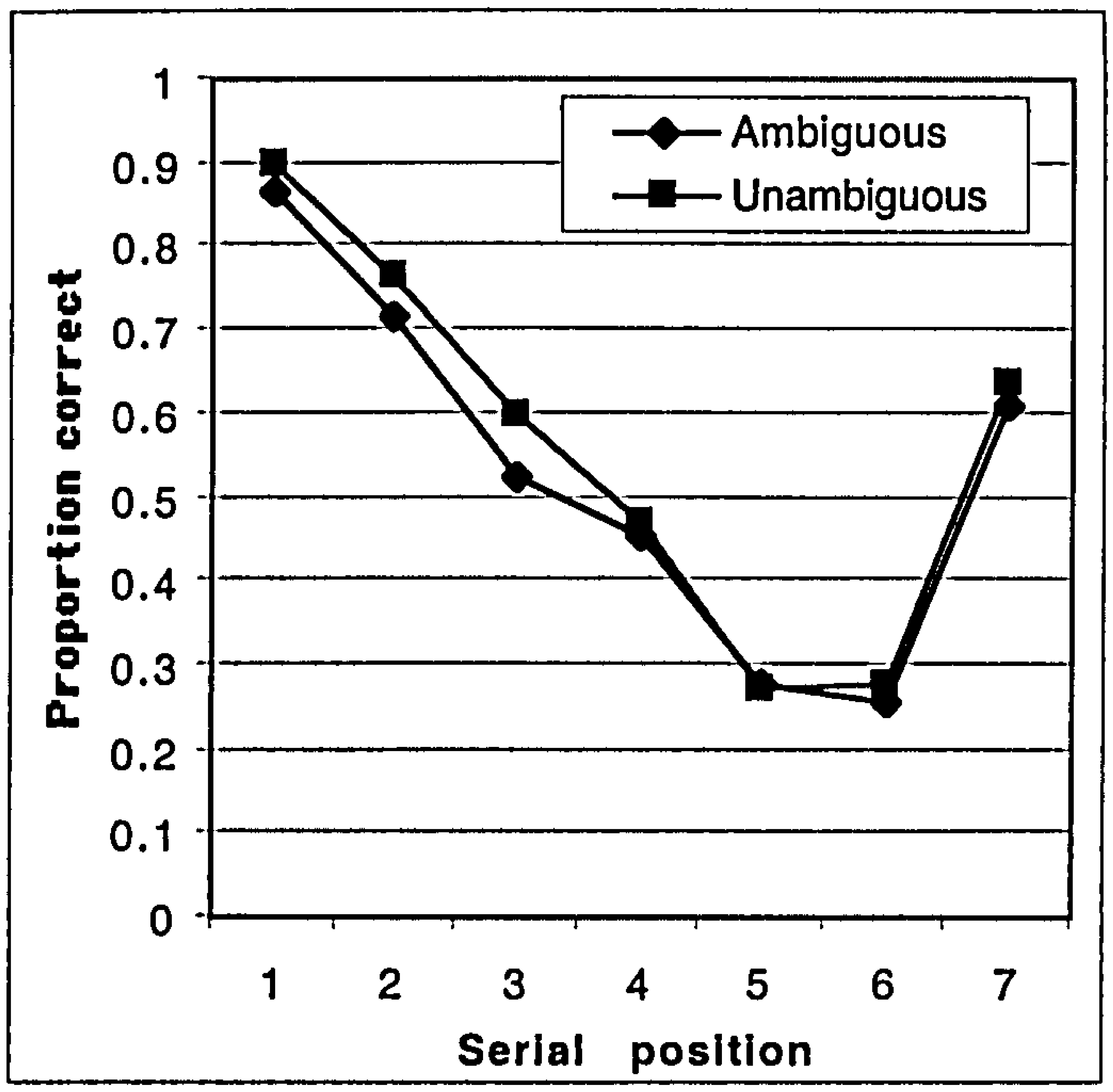


Figure 3.1. Recall as a function of ambiguity and serial position

The Serial Recall data were entered into a two-way within participants ANOVA, in which the independent variables were ambiguity and serial position. This revealed a statistically significant effect of serial position (F (6,102) = 101.23, $p < .001$). However, the effect of ambiguity was not significant (F (1,17) = 3.50, $p = .073$). In addition, the ambiguity x serial position interaction was also not significant (F (6,102) = 1.22, $p = .301$).

These analyses indicate that there were no significant effects of semantic ambiguity on recall. However, there does appear to be a weak trend towards an advantage for ambiguous words. In order to examine this in more detail, response types were categorised and converted into proportions of the total number of responses. The results are displayed in Table 3.2. For a more detailed discussion of error classification, see previous experiments.

Word set	Correct	Errors						
			Item Errors					
		Order	Total Item	Omissions	ISI	IEI	EEI	PA
Amb	.530	.152	.317	.261	.034	.002	.002	.017
Unamb	.561	.161	.278	.237	.025	.001	.002	.013

Table 3.2. Response patterns in Serial Recall for each word set

The rate of conditionalised order errors (proportion per item recalled) was .228 for ambiguous words and .226 for unambiguous words, a difference that was not significant ($\underline{t}$ (25) = .14, $\underline{p}$ = .893). An analysis of item errors revealed a significant effect of ambiguity ($\underline{t}$ (25) = 3.17, $\underline{p}$ < .01). A series of analyses were also performed on the item error subtypes. A significant effect of ambiguity on omission errors was observed ($\underline{t}$ (25) = 2.13, $\underline{p}$ < .05). However, the effect of ambiguity on phonological approximation error rates was not significant ($\underline{t}$ (29) = .90, $\underline{p}$ = .377). Similarly, there were non-significant effects of ambiguity on intra-set intrusion errors ($\underline{t}$ (29) = 1.64, $\underline{p}$ = .114). The frequency of intra-experiment and extra-experiment intrusions was very low, so will not be discussed further.

Semantic ambiguity appears to have no influence on the retention of order information. However, in contrast to the overall null effect of ambiguity on Serial Recall performance, this variable did significantly affect item error rates. Specifically, more omission responses were made to lists of ambiguous words, than to lists of unambiguous words.

3.3.3 Analysis of Performance on the Language Tasks

Auditory Lexical Decision

By-participant and by-item analyses were performed on the Lexical Decision data, with ambiguity as the independent variable. Ambiguity had a significant effect on performance in the by-participants analysis (t (25) = 5.13, p < .001), but not in the by-items analysis (t (44)= 1.11, p = .272). This represents a partial replication of the findings of Rodd et al. (2000).

To further examine the pattern of Lexical Decision performance, an error analyses was undertaken. The proportion of incorrect responses made by participants was reasonably low, at 6.52% overall. More errors were made on unambiguous words (7.36%) relative to ambiguous words (5.69%), although this difference is small and not significant by participants (t (25) = .131, p = .203) or by items (t (44) = .54, p = .592).

Word Identification in Noise

The WIN data were subjected to by-participant and by-item analyses, with ambiguity as the independent variable. The participants two-tailed t-test analysis revealed a statistically significant effect of ambiguity on performance (t (25) = 5.05, p < .01). Participants were able to correctly identify unambiguous words in higher levels of noise, relative to ambiguous words. However, in the items analysis, the effect of ambiguity was not significant (t (44) = .92, p = .363).

Speech Rate

Finally, by participant and by item analyses were performed on the Speech Rate data, with ambiguity as the independent variable. The participants analysis revealed no significant effect of ambiguity on Speech

Rate (t (17) = .65, p = .383). Similarly, the items analysis was also not significant (t (44) = .12, p = .908).

3.3.4 The Effect of Related Senses on Memory and Language Task Performance

Before moving on to the regression analyses, it is of interest to examine the effects of a second variable identified by Rodd et al. (2000, 2002), that of related senses. This variable was not explicitly manipulated in the present experiment, indeed, the test items were all drawn from the Rodd et al. (2000) low sense set. However, it was decided that there was sufficient variation in the number of related senses items had to warrant an investigation of this type.

The item set was split at the median on the basis of the number of related senses each word had (according to the Wordnet Online Database), with the results being displayed in Table 3.3. Item analyses revealed these 'low sense' and 'medium sense' sets to be equivalent on Speech Rate, length, phonemes, familiarity, concreteness, and frequency.

	Low Sense	Medium Sense
No. Items	23	23
No. Related Senses	2-4	5-8
Ambiguous Items	10	13
Unambiguous Items	13	10
ALDT (ms)	358.03 (105.89)	342.13 (97.66)
WIN (mean round ID)	2.92 (0.31)	2.67 (0.30)
ISR (% correct)	52.65 (11.43)	56.47 (11.78)
Speech Rate (w/s)	3.22 (0.58)	3.24 (0.58)

Table 3.3. Summary of the low and medium sense item sets, and means (and standard deviations) for language and memory task performance

It is apparent that performance on the three tasks does differ as a function of the number of related senses a word has. Serial recall performance does show a small advantage for medium relative to low sense words. Furthermore, positive effects of this variable are apparent in Word Identification in Noise and Lexical Decision, effects comparable to those of ambiguity reported earlier. These data will now be discussed in turn.

3.3.4.1 Immediate Serial Recall

Performance on low and medium sense items at each serial position can be observed in Figure 3.2. It can be seen that performance on both word sets follows similar serial position curves, with large primacy and recency effects. Medium sense words appear to show a small advantage over low sense words at every position except the first. This difference is particularly large at the last two serial positions.

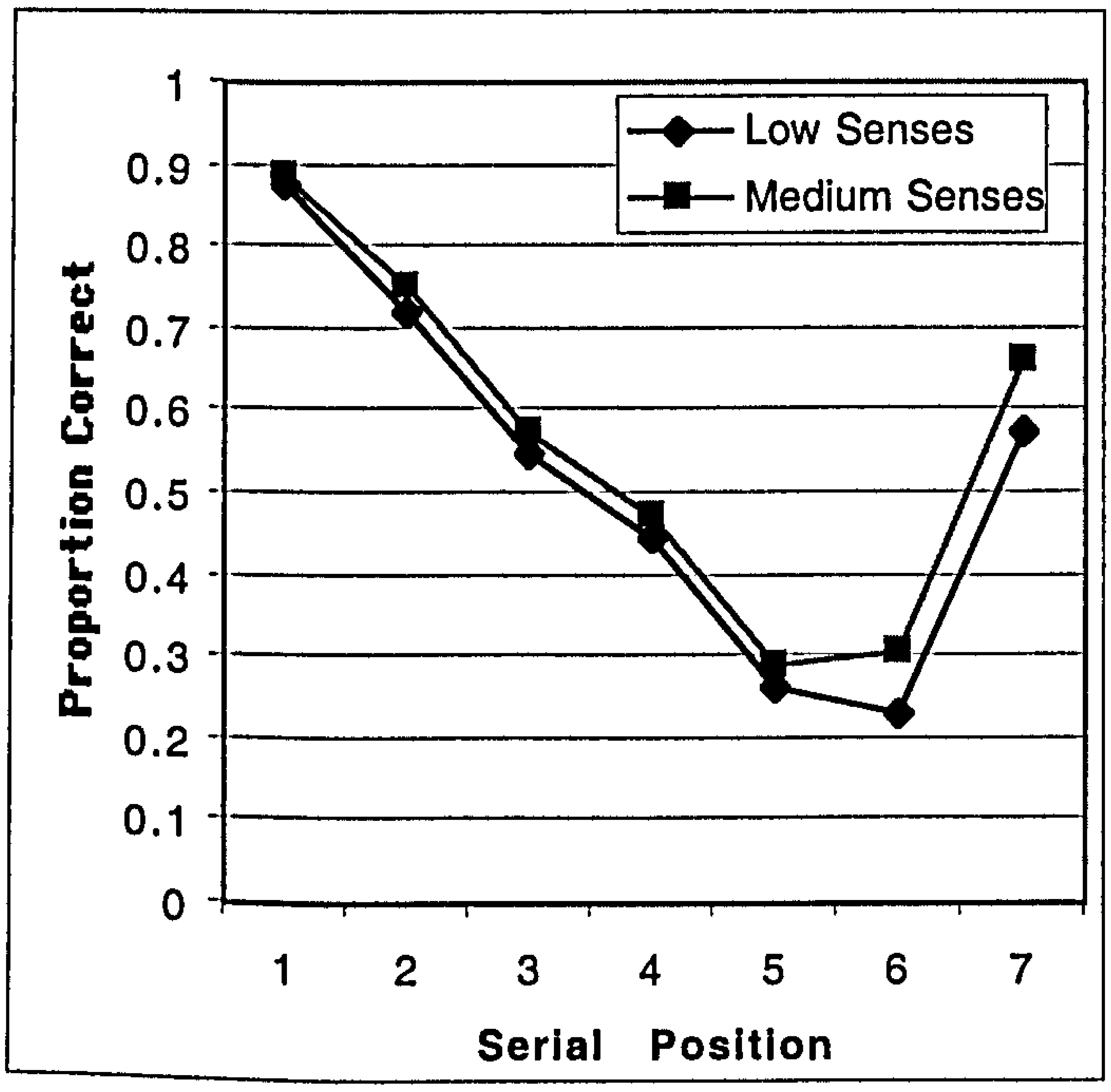


Figure 3.2. Recall as a function of no. related sense and serial position

A two-way ANOVA was performed on the recall data, with serial position and sense set as the factors. This produced significant effects of position (F (6,150) = 98.53, p > .001) and senses (F (1,25) = 24.59, p < .001). The interaction was not significant (F (6,150) = 1.58, p = .156), suggesting that this sense advantage does not differ as a function of serial position. The lack of an interaction also confirms that the sense effect is not simply the result of recency effects.

3.3.4.2 Language Task Performance

Auditory Lexical Decision

As noted in Table 3.4, participants' responses in the Lexical Decision task were slower to low than to medium sense items. The participant data was entered into a two-tailed paired t-test, with Lexical Decision reaction time (from offset) as the dependent variable. This revealed that the sense effect was not significant (t (25) = 1.91. p = .067). When entered into an items t-test, the effect remained not significant (t (44)= .66, p = .512).

Of the responses made to medium sense items, 4.35% were incorrect. This compares with an error rate of 8.7% on low sense words. Analyses revealed this difference to be significant for participants (t (25) = 2.89. p < .01), but not items (t (44) = 1.09. p = .282).

Word Identification in Noise

A facilitatory effect of senses on WIN, similar in scale to the inhibitory effect of ambiguity, is illustrated in Table 3.4. The participants data was entered into a two-tailed paired t-test, and a significant effect of senses was revealed (t (25) = 4.42, p < .001). However, the effect was not significant in the by-item analysis (t (44) = .97, p = .337). Nevertheless, participants were generally able to identify medium sense items in higher noise levels.

Speech Rate

There were no significant effects of senses in the participants ($\underline{t}$ (25) = .76, $\underline{p}$ = .453) or items ($\underline{t}$ (44) = .31, $\underline{p}$ = .759) analyses.

It can be concluded that the related senses variable did influence perceptual and input processing. However, the effect on Lexical Decision reaction times was marginally not significant (although error rates were affected), and did not extend to the items analyses in either task. In contrast, senses had a substantially greater and more robust effect on Serial Recall processing, extending across participant and item analyses.

3.3.5 Analysis of the Relationships between Language Processing Measures and Immediate Serial Recall

A Lorch and Myers (1990) Method 3 regression analysis was performed on the data, with Serial Recall as the dependent variable. Each participant's raw score on each item in each task was entered, with the aim of examining possible predictors of STM within each participant's performance. In this experiment, Auditory Lexical Decision, Word Identification in Noise, Speech Rate, and voiced item length were entered as predictors into a simultaneous linear regression. The results are displayed in Table 3.4.

Variable	t	Unique R_2	Sig t
Item Length	.385	.000	.7004
Auditory Lexical Decision	.465	.000	.6423
Word Identification in Noise	.283	.000	.7769
Speech Rate	2.126	.003	.0338

Table 3.4. Within-participant item regression analysis with Serial Recall as the dependent variable

The regression reveals that neither of the two input tasks predicts unique variance in Serial Recall performance. Similarly, item length is not related to ease of recall in this experiment. However, Speech Rate does account for unique variance in Serial Recall. The speed with which a participant can rapidly articulate a word predicts how well they can remember that word in the short-term memory task.

3.4 Discussion

In contrast to the effects of concreteness uncovered in previous experiments, semantic ambiguity did not significantly influence overall Serial Recall performance, at any list position. However, the effect was marginally non-significant, and an error analysis did reveal that significantly more omission errors were made on ambiguous word lists. Inhibitory ambiguity effects were observed in Auditory Lexical Decision and Word Identification in Noise, although these were only significant in the by-participant analyses. No effect of ambiguity was observed in Speech Rate.

A post-hoc analysis revealed further variations in performance, on the basis of the number of related senses a word had. After collapsing the data across original word sets and instead examining items classed as having a medium number of senses or a low number of senses, beneficial and significant effects of related senses emerged in recall. Similarly, related sense effects were observed in Word Identification in Noise, that were significant in the participants analysis. The effect on Lexical Decision was marginally non-significant, although significantly more errors were made in response to items from the low sense set. Again, Speech Rate was not influenced by number of related senses.

Finally, the Lorch and Myers (1990) regression revealed that Speech Rate was the only significant predictor of unique variance in Immediate Serial Recall. Neither item length nor performance in either of the two input tasks was related to verbal short-term memory.

The observation that Lexical Decision reaction times were longer for ambiguous words, relative to unambiguous words, represents a replication of the findings reported by Rodd et al. (2000) using the same items. This supports the account provided by connectionist models (e.g. Gaskell & Marslen-Wilson, 1997; Hinton & Shallice, 1991; Plaut & Shallice, 1993), that semantic competition occurs in response to activation of input phonology representations. In Auditory Lexical Decision, this competition would increase the time taken for a stable activation to be produced and as a consequence would slow recognition and response times. It is important to note however, that the Rodd et al. (2000) findings were not fully replicated, as in this experiment the ambiguity effect was only significant in the participants analysis. As the same number of participants was tested on the same task, using the same sound-files as in Rodd et al., the reasons for this are unclear.

A similar pattern of results was uncovered in the second input task, Word Identification in Noise, with participants correctly identifying unambiguous words when embedded in higher levels of white noise, relative to performance on ambiguous words. This indicates the inhibitory ambiguity effect (Rodd et al., 2000) to be sufficiently reliable and robust to enable extension to different measures of word recognition. Word Identification in Noise involves the comparison of auditory input with representations within input phonology, with the representations with the highest resting activation and closest match to the stimuli being selected as response candidates. Activation is then fed to the semantic system, where competition occurs between representations. This would be inconsistent for ambiguous words, and would take longer to become stable. As a consequence, activation conveyed back to input phonology would be delayed and inconsistent, meaning that phonologically similar but incorrect items may be selected for response.

In contrast to these recognition findings, Speech Rate performance was not affected by the ambiguity variable. This differs from the effects of concreteness reported in Experiments One and Three (when the item set was a sufficient size). This would suggest ambiguity to be a variable only influencing the input pathway. Indeed, the semantic competition account of inhibitory ambiguity effects would not be predicted to influence Speech Rate performance. Although Speech Rate may be affected by semantic processing (as evidenced by concreteness effects), the existence of unrelated meanings of a word would not hinder performance.

The effects of semantic ambiguity on Immediate Serial Recall are less clear. A small, marginally non-significant, recall advantage of around 3% is apparent for unambiguous words. Ambiguity did however have a significant influence on error rates, with more omission responses made to ambiguous word lists. It would appear that ambiguity does have a small effect on certain aspects of verbal short-term memory. As indicated by the findings in the language measures, the inhibitory ambiguity effect may arise only at interactions between input phonology and semantic representations. Therefore, the influence of ambiguity on Serial Recall may reflect the relative role and importance of the speech input pathway in temporary verbal memory.

At list presentation, representations within input phonology pertaining to the test items would be activated. These in turn would access semantic representations, resulting in inhibitory competition for ambiguous words. This would mean that input phonology and semantic representations would be less stable and mutually supportive throughout encoding and temporary storage, leading to an advantage for unambiguous word lists.

However, the ambiguity effect was small, relative to concreteness, and marginally non-significant overall. This may reflect the notion suggested in previous chapters, that the input pathway is comparatively peripheral in terms of temporary verbal storage and retrieval. Thus, it is plausible that the small ambiguity effect arises through the involvement of input processing, while the larger concreteness effect emerges primarily due to the more critical role of the output pathway in Serial Recall.

Also of interest were the effects of related senses that were uncovered in the post-hoc analysis. According to the Kawamoto (1993) network, a cluster of related senses would create a broad and shallow basin of attraction, enabling faster settling times. Alternatively, comparisons can be made between the sense effect and concreteness (Rodd et al., 2000, 2002). As with concrete words, words with many related senses may be semantically rich, either with a greater number of features (Plaut & Shallice, 1993), a greater ease of predication (Jones, 1985), or a more efficient availability of contextual information (Schwaneflugel, Harnishfeger, & Stowe, 1988). This advantage in the set-up of the semantic network would result in related sense effects in measures of input and output processing.

In line with this, beneficial effects of related senses were observed in Word Identification in Noise, thus extending the findings of Rodd et al. (2000, 2002) to a new task. The effect on Lexical Decision reaction times was marginally non-significant, although error rates did vary significantly between word sets. This lack of a significant effect on response times may be due to the invariance in number of senses between words, relative to the Rodd et al. study. As all items in this experiment were taken from their low sense set, the difference in number of senses between medium and low sense sets was inevitably small. Nevertheless, the trend towards an effect in Lexical Decision, and the significant effect in Word Identification in Noise, indicates the sense effect to be robust enough to be evident even within Rodd et al.'s item sets. In addition, the opposite effects of ambiguity and related senses that emerged in these tasks refutes the claim made by Klein and Murphy (2001) that there are no representational differences between homonyms and polysemous words.

The invariance in number of senses between item sets may also account for the lack of significant effects on Speech Rate performance. It has already emerged in previous experiments that semantic variables may be more likely to influence Speech Rate with larger item sets. Similarly, the subtle variation in number of senses between the reclassified sense sets may not have been of a sufficient magnitude to influence this relatively semantic-insensitive task. Interactive production theory (e.g. Dell, 1986; Dell et al., 1997) would predict the emergence of sense effects in Speech Rate with greater variation between item sets. This would be in line with the observation of significant polysemy/sense effects in word naming (Hino & Lupker, 1996; Lichacz et al., 1999).

The small (around 4%) but significant effect of senses on Immediate Serial Recall is an interesting finding, particularly as the word sets were not divided on the basis of senses. This meant that word lists often included a mixture of items with medium and low numbers of senses, a situation that often reduces or abolishes variable effects. This sense effect may emerge through the varying influences of many aspects of the speech processing system on verbal short-term memory. The temporary storage and processing of information within the input pathway would possibly contribute to concreteness and sense effects and also be the sole cause of less robust inhibitory ambiguity effects in Serial Recall. The potentially more central role for the output pathway would further contribute to sense effects and would also be the primary source of concreteness effects in Serial Recall.

As noted, there are problems associated with a post-hoc analysis such as this. The examination of mixed Serial Recall lists, often containing words from both medium and low sense sets, means that the presentation of each item was not controlled for each participant. The difference in the number of senses between sets was also low. However, these problems would be expected to operate against the emergence of significant effects, rather than artificially inflate them.

A further problem concerns the measure of number of senses that was used. Palmer (2000) has questioned the ability of on-line lexical resources such as WordNet (Miller, 1990; Miller & Fellbaum, 1991), the database used in this experiment, to give an accurate criteria to sense distinctions. Palmer argued that WordNet has a tendency to be too fine-grained in its division of senses. This would have implications for the sense set classification applied in this experiment, particularly as the variation in number of senses was small to start with. Nevertheless, it is still of interest that words classed as having a greater number of related senses produced improved performance in memory and language tasks in this experiment.

Finally, the results of the regression analysis support the notion that, although speech processing generally is involved in Serial Recall, it is the output pathway that may be of primary importance. Neither spoken item length nor either of the speech input tasks predicted short-term memory performance. While the input pathway would logically be involved to some extent in verbal memory tasks, these findings suggest the capacities critical to Lexical Decision and Word Identification in Noise to be less so in Serial Recall.

However, the speed with which participants could rapidly articulate a word was related to their recall of that word. This is in line with the results of Experiment One (although Speech Rate did not predict recall in the second and third experiments). This would suggest the output mechanisms underlying performance in Speech Rate (e.g. activation and maintenance of output phonology, selection and implementation of articulatory programs) to be important in supporting Serial Recall.

3.5 Chapter Summary

The influence of the language processing system in verbal short-term memory was examined by administering two measures of word recognition along with Serial Recall and Speech Rate, and manipulating semantic ambiguity. In line with the findings of Rodd et al. (2000, 2002), inhibitory effects of ambiguity were observed in Lexical Decision and Word Identification in Noise. Although the overall effect on short-term memory performance was marginally non-significant, an error analysis did reveal significant adverse effects of ambiguity on omission error rates. A post-hoc analysis then identified the influence of a second variable discussed by Rodd et al., that being the number of related senses a word has. Beneficial sense effects were observed in Word Identification in Noise, along with marginally non-significant effects in Lexical Decision. Furthermore, a small but significant advantage for words with a medium number of senses was observed in Immediate Serial Recall. The Lorch and Myers (1990) regression then revealed that Speech Rate was the only unique predictor of recall performance in this experiment. In contrast, Lexical Decision and Word Identification in Noise performance was not significantly related to Immediate Serial Recall.

These results provide an interesting insight into the interactions between phonology and semantics in the processing of speech input, and give an indication of how these processes may be involved in temporary verbal memory. Overall, the varying influences of ambiguity and polysemy on Serial Recall supports the notion that different language-based representational capacities are involved in short-term memory. It may be that the inhibitory ambiguity effect is a semantic variable that only emerges during input processing. The relatively small and unreliable effect it has on Serial Recall may therefore reflect the degree to which the input pathway is central to verbal short-term memory. In contrast, the number of senses a word has would be predicted to beneficially influence speech perception and production (although this was not fully demonstrated in the present experiment, due to the post-hoc nature of the analyses). The significant effect of this variable on Serial Recall may emerge through the underlying operation of both input and output processing in this task.

The findings constitute further tentative evidence in support of the idea that, while all aspects of speech processing are involved in temporary verbal memory, it is mechanisms within the speech output pathway that may be of primary importance. The results of the regression analysis upheld this view, as they suggest that the processing capacities underlying the rapid and repeated production of words were important in determining recall proficiency of those same words.

Chapter Four

The Effects of Concreteness on Speech Input and Output Measures and Verbal Short-Term Memory in a Single Experiment

The effects of the semantic variables that were observed and discussed in previous chapters provide a number of insights into language and memory functioning. The varying influence of factors such as concreteness, ambiguity, and related senses, indicate how different forms of linguistic information are handled by, and interact within, the processing system responsible for speech and short-term memory. Importantly, these findings and the regression analyses enable a more detailed discussion of the functional connections between temporary verbal memory and speech processing, including how they are linked and which aspects of one are more central to the other.

While the four experiments already discussed each contribute interesting insight, a greater understanding then emerges as the different experimental findings are assembled together to form a wider and more detailed image of the memory and speech processing system. However, this may be somewhat fragmentary, as it involves different sets of participants and experimental items. This is potentially problematic, particularly as item set size does vary considerably between experiments, and a lack of significance in items analyses has emerged in certain tasks.

A more cohesive and powerful argument can be developed from the results of a single large-scale experiment, using multiple measures of speech processing. Therefore, Experiment Five involved administering a more comprehensive series of language tasks, using the same (relatively large) item set in each, to a single group of participants. All the language tasks featured in this experiment had been administered in at least one of the previous experiments, and concreteness was again the variable that was manipulated.

4 Concreteness in a Large-scale Experiment using Multiple Language Measures

4.1 Introduction

The aim of this experiment was to develop a comprehensive picture of speech processing and verbal memory within a single item and participant set. In four previous experiments, concreteness effects have already been observed in Serial Recall and Definition Naming, along with smaller effects in Speech Rate and Gating. In contrast, significant effects have not emerged in Repetition and Lexical Decision. A series of regression analyses in these experiments established that Definition Naming and occasionally Speech

Rate were the only significant predictors of memory performance. It was of interest to examine whether a similar pattern of results would emerge in a single experiment, using larger sets of items and participants.

To this end, Experiment Five featured two measures of word recognition, three measures of word production, and the standard Immediate Serial Recall memory task common to all the present experiments. The input measures consisted of Auditory Lexical Decision and Word Identification in Noise. Concreteness effects were not observed on Lexical Decision in Experiment Three, in contrast to previous findings (e.g. Tyler et al., 2000). A replication of this null effect using a greater number of participants and items would build the case for a word recognition process functioning without the influence of concreteness.

In Experiment Four, significant effects of both ambiguity and related senses were observed in Word Identification in Noise, indicating it to be a task requiring semantic support for successful performance. This may predict an advantage for concrete words on this measure, particularly if concreteness and related senses are represented in similar ways (as argued by Rodd et al., 2002). Alternatively, there may be differences in how concreteness and related senses affect the structure of the conceptual system. Nevertheless, this use of multiple measures, tapping different aspects of input processing, reduces the likelihood of failing to detect a hidden but active influence of concreteness on perceptual processing.

Concreteness effects of varying magnitudes have already been observed on two production measures, namely Definition Naming, and Speech Rate. The pattern and size of these effects, and the absence of significant effects in Repetition, have been taken to reflect the nature of semantic influences on different aspects of the output pathway, and the possible processing capacities critical to each measure. However, these tasks were not administered within the same experiment, and so variations in item set size and content remain an issue. The use of these three tasks within a single experiment, using the same item set, enabled a direct comparison of performance patterns within these production measures, and between input and output tasks. Together, Definition Naming, Repetition, and Speech Rate provide a fairly comprehensive mapping of the speech output pathway, from semantic processing to articulation.

Although successful performance requires accurate and efficient articulation, Definition Naming is primarily a measure of access to, and selection of, output phonology from initial semantic activation, via lemma nodes. In contrast, Speech Rate and Delayed Repetition tap various aspects of phonological and articulatory processing, although they have indicated some influence of support from semantic activation. This would cascade down the output pathway, as suggested by models such as Dell (1986; Dell et al., 1997).

A second measure of Definition Naming performance (reaction time) was introduced in this experiment. Effects of concreteness on both correct response rates and reaction times would indicate the reliability of the influence this semantic variable has on speech production. Furthermore, the introduction of a timed element to the task makes it somewhat more online, meaning participants have to respond as quickly as possible, rather than consider their response at leisure as in the first two experiments.

The Lorch and Myers (1990) regression analyses used in previous experiments involved language tasks that tapped certain aspects of speech processing. Although interesting insights into verbal memory have already developed as experiments were performed and the results compared, these comparisons were often indirect with tasks not examined as predictors in the same analysis. The collection and use of these tasks in a single experiment enabled a regression analysis in which tasks measuring many wide-ranging aspects of both speech input and output processing were entered into a single analysis. From such an analysis, it was hoped that the speech processing capacities most critical to verbal short-term memory would be identified. On the basis of previous experiments, it was predicted that Definition Naming and Speech Rate performance would be the potential predictors most closely related to Immediate Serial Recall.

4.2 Method

4.2.1 Participants

Thirty University of York undergraduates and postgraduates took part, receiving course credit or payment for their participation. There were 9 men and 21 women, with an age range of 18-28 years.

4.2.2 Materials

The item set consisted of 68 single syllable words, divided equally on the basis of rated concreteness. Of these items, 48 were drawn from the Experiment 5 test set, with 11 more items being selected from a larger set rated by participants in preparation for that study. To complete the set, a group of 15 participants were asked to give concreteness, age of acquisition, and frequency ratings for an additional 20 words drawn from the MRC Psycholinguistic database. From this supplementary procedure, 9 new items were selected. Although the number of related senses varied between each item, it was ensured that all words had one central meaning (i.e. no semantically ambiguous items were used).

The concrete and abstract word sets were matched for rated age of acquisition, rated word frequency, Kucera-Francis word frequency, familiarity, number of phonemes, and number of letters. The experimental items and their values are provided in Appendix F.

Definitions for these words were selected from the Oxford and Collins English dictionaries, the Online Wordsmyth Educational Dictionary-Thesaurus (Parks et al., 1998), and the WordNet online lexicographic database (Miller, 1990; Miller & Fillbaum, 1991). Where more than one sense was available, the most frequent and semantically relevant definition was selected. A group of independent judges rated the accuracy and suitability of each definition, on a scale of 1-5. An analysis of variance revealed no significant difference in definition accuracy/suitability between the two word sets ($F(1,67) = .022$, $p = .883$). Definitions are provided in Appendix G.

For the Lexical Decision segment of the experiment, wordlike nonwords were created, by taking moderate frequency real words and altering one phoneme. The nonwords had a similar distribution of word lengths to the test stimuli.

All stimuli (test and practice items, nonwords, and definitions) were recorded onto a Sony minidisk recorder by an English speaking female. They were then transferred onto a Macintosh computer.

4.2.3 Procedure

A similar design to previous experiments was used, in that each participant performed each task, with the same 68 items featured in each. Due to their nature, the six tasks were administered in a fixed order to each participant, over three sessions of 45 minutes. Auditory Lexical Decision and Word Identification in Noise were administered in session 1, Definition Naming and Delayed Repetition in session 2, and Immediate Serial Recall and Speech Rate in the final session. Effort was made to ensure a considerable interval between testing days, with most participants performing one session a week, over three weeks.

Auditory Lexical Decision (ALD) Testing followed the same procedure as in Experiments Three and Four. In this experiment, 20 practice items preceded the test phase, which consisted of 68 words and 68 nonwords presented to the participant in random order.

Word Identification in Noise (WIN) The preparation and testing procedures followed those used in Experiment Four, with the same energy levels, white noise durations, and signal-to-noise ratios. The only difference was the presentation of 68 items in each round, and the use of a suitably larger response booklet.

Definition Naming (DN) This task was controlled using the PsyScope program on a Macintosh computer. Each trial commenced with an 'O' fixation point presented in the centre of the monitor screen. Once the participant was ready to proceed, they pressed the space bar (hence the task is self-paced). After a 500 ms delay, the definition was aurally presented through a Fostex speaker. Immediately following the end of the definition, an 'X' cue was presented at the centre of the screen. This remained in view until a vocal response was made, or until the trial timed out (after 15 seconds). The 68 test trials were presented in random order, following 6 practice trials.

The participant was asked to listen carefully to each definition, and respond with the relevant word as quickly as possible following cue presentation. Reaction time was classed as the delay between cue presentation and response onset, and was recorded through an Audio-Technica microphone. In addition, the experimenter recorded the participant's actual responses. Following the practice trials, no feedback was given at any point.

Delayed Repetition (REP) Presentation was controlled using a similar procedure to the one described in Experiment Three. However, Immediate

Repetition was not assessed in this experiment, with the result that each item was presented in two trials, after 1000 ms and 3000 ms delays. This entailed a total of 12 practice trials and 136 test trials.

Immediate Serial Recall (ISR) Testing was performed using the same digitised stimuli featured in the Lexical Decision, Word ID in Noise, and Delayed Repetition tasks. Each of the two word sets (Concrete and Abstract) was presented in their own 34 list series, with seven items in each list. The presentation procedure and pseudo-randomisation constraints used in the previous experiments were again implemented.

Speech Rate (SR) Finally, the Speech Rate task was administered, using the procedure described in previous chapters.

4.3 Results

4.3.3 Summary of Task Performance

	Concrete	Abstract
Immediate Serial Recall (%)	60.06 (12.96)	53.08 (15.21)
ALDT (ms)	317.79 (79.09)	310.27 (74.56)
WIN (mean round ID)	2.74 (.32)	2.79 (.37)
Definition Naming		
% Correct	73.53 (15.60)	46.67 (12.16)
RT of correct responses(ms)	1237.18 (411.97)	2140.72 (924.77)
Delayed Repetition		
1 sec delay	440.82 (61.59)	442.03 (64.25)
3 sec delay	371.72 (48.55)	377.93 (48.35)
Total (mean)	406.27 (50.85)	409.98 (53)
Speech Rate (words/sec)	3.35 (.63)	3.28 (.58)

Table 4.1. Means (and standard deviations) for performance on speech processing tasks for each word set

It can be seen from Table 4.1 that concreteness has varying effects on performance in the different tasks. Lexical Decision response times made to concrete words appear to be slightly slower than those made to abstract words. However, in the other recognition task (Word Identification in Noise), there is a small beneficial effect of concreteness.

Perhaps the largest effect of concreteness in this experiment can be observed on Definition Naming. Participants successfully named to definition many more concrete than abstract words. In addition, when they did answer correctly their responses to abstract words were much slower than to concrete words (nearly twice as long, on average).

In the other production task (Delayed Repetition), a very small concrete advantage can be observed. It appears that participants were slightly quicker in repeating concrete than abstract items at both delays, and overall. However, this difference is perhaps negligible, with the largest mean difference being just over 6 ms (for Rep 3). Similarly, the concreteness effect on Speech Rate is also relatively small, with participants producing a slightly higher words-per-second production rate on concrete than abstract items.

In contrast to this, a large concreteness effect (of around 7%, on average) on Immediate Serial Recall performance is apparent. This is illustrated further in Figure 4.1.

4.1.1 Immediate Serial Recall

The recall data were plotted as a function of proportion correct at each serial position, as illustrated in Figure 4.1. Bowed curves are evident for both item sets, with large primacy effects and smaller recency effects. Furthermore, an advantage for concrete words is apparent at all seven positions, particularly positions 2-6.

A 2x7 repeated measures ANOVA on Serial Recall performance, with concrete and serial position as variables, revealed a significant effect of concreteness on performance ($F(1,29) = 26.84$, $p < .001$). The effect of position was also significant ($F(6,174) = 152.98$, $p < .001$). The concreteness x position interaction was also significant ($F(6,174) = 2.48$, $p < .05$). Analysis of simple effects revealed that the concreteness effect was significant at every list position, except the final one ($F(1,29) = .86$, $p = .360$).

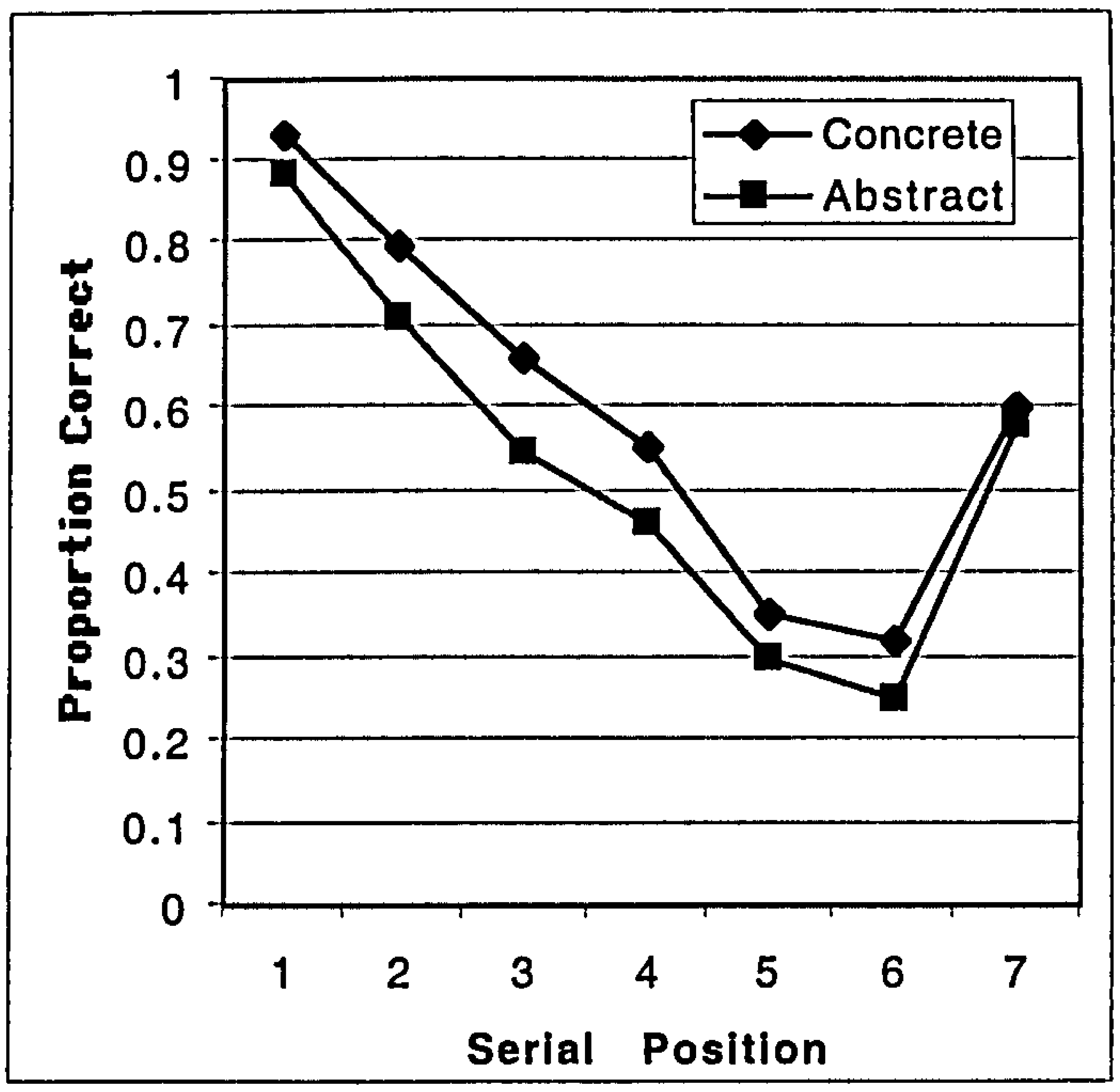


Figure 4.1. Recall as a function of concreteness and serial position

It is apparent that participants made more errors on lists of abstract than concrete words. In order to examine this in more detail, response types were categorised and converted into proportions of the total number of responses, using the classification system described earlier. The results for each item set are displayed in Table 4.2.

		Errors						
			Item Errors					
Word set	Correct	Order	Total Item	Omissions	ISI	IEI	EEI	PA
C	.601	.153	.247	.191	.043	.004	.002	.007
A	.531	.165	.304	.220	.051	.001	.004	.028

Table 4.2. Response patterns in Serial Recall for each word set

The conditionalised rate of order errors was .208 on concrete words and .247 on abstract words, a significant difference (t (29) = 2.75, $p < .05$). A significant effect of concreteness was apparent on the overall proportion of item errors (t (29) = 5.88, $p < .001$). A series of analyses were also performed on the item error subtypes. A significant effect of concreteness on omission errors was observed (t (29) = 2.77, $p < .05$), as there was on phonological approximation error rates (t (29) = 7.35, $p < .001$). However, analyses produced non-significant effects of concreteness on intra-set intrusions (t (29) = 1.43, $p = .165$), intra-experiment intrusions (t (29) = 1.43, $p = .164$), and extra-experiment intrusions (t (29) = 1.66, $p = .107$).

Participants made more order and item errors on abstract words than on concrete words. The difference in item error rates between the two sets was due to variations in the probability of omission errors and phonological approximation errors. It is apparent that concreteness has robust positive effects on Serial Recall performance. The effect of this variable on performance in the word recognition and production tasks will now be examined.

4.3.3 Analysis of Performance on the Language Tasks

Auditory Lexical Decision

The sound-files for the concrete items were, on average, 55 ms shorter than the abstract items sound-files, a significant difference (t (66) = 2.94, $p < .01$). Such a difference would particularly influence Lexical Decision performance, as the quicker a word is spoken, the earlier in time it can be recognised. Therefore, to control for this potential problem, reaction time from item offset was used as the measure of Lexical Decision performance. The effect of concreteness on this measure was not significant (t (29) = 1.15, $p = .258$).

In addition, a by-items analysis was carried out on the Lexical Decision (from offset) data. This revealed a non-significant effect of concreteness (t (66) = .53, p = .597).

An analysis of the error rates in Lexical Decision was then undertaken. The overall error rate was 7.6%, with 6.47% of responses to concrete words being incorrect, and 8.73% of responses to abstract words incorrect. This effect was not significant (t (29) = 1.88, p = .071). Similarly, the difference in error rates was not significant in the items analyses (t (66) = 1.13, p = .264).

Word Identification in Noise

The small concreteness advantage in Word Identification in Noise was not significant across participants (t (29) = .97, p = .340) or items (t (66) = .28, p = .782).

Definition Naming

Two measures of Definition Naming performance will be reported in this experiment: the rate of correct responses and correct response reaction times. It is important to note that the reaction time measure only involves around 60% of the possible data (i.e. the times for correct responses only). Although data for incorrect responses may be of some potential interest, they are by definition measuring the time taken to retrieve and produce words not in the test set. As the primary interest here is in how efficiently and successfully the specific test words are produced, reaction times for other words do not address the relevant questions.

Concreteness had significant effects on correct response rates ($\underline{t}$ (29) = 11.71, $\underline{p}$ < 001) and on the reaction times for correct responses ($\underline{t}$ (29) = 6.90, $\underline{p}$ <. 001).

A significant effect of concreteness on correct responses ($\underline{t}$ (66) = 5, $\underline{p}$ < .001) was also revealed in the by-item analysis. Finally, the effect of concreteness on correct response reaction times was also significant in this analysis ($\underline{t}$ (66) = 6.62), $\underline{p}$ < .001).

Delayed Repetition

A 2x2 repeated measures ANOVA was performed on the Delayed Repetition data, with concreteness and delay length as the factors. This revealed a marginally non-significant effect of concreteness ($\underline{F}$ (1,29) = 3.99, $\underline{p}$ = .055). The effect of delay length was significant ($\underline{F}$ (1,29) = 78.01, $\underline{p}$ < .001), while the concreteness x delay interaction was not ($\underline{F}$ (1,29) = 1.53, $\underline{p}$ = .225).

A by-item ANOVA revealed a significant effect of delay ($\underline{F}$ (1,135) = 291.67, $\underline{p}$ < .001), but not concreteness ($\underline{F}$ (1,135) = .988, $\underline{p}$ = .322). The concreteness x delay interaction was not significant ($\underline{F}$ (1,135) = .335, $\underline{p}$ = .564).

Speech Rate

Analysis revealed a significant effect of concreteness on Speech Rate in the across participants ($\underline{t}$ (29) = 4.37, $\underline{p}$ < .001), but not across items ($\underline{t}$ (66) = 1.19, $\underline{p}$ = .239).

To summarise the results of these analyses, it is apparent that concreteness has a robust effect on performance in the Immediate Serial Recall task, for both participants and items. In addition, this semantic variable also has a beneficial influence on speech production performance. Significant and substantial effects were observed in Definition Naming, on both the likelihood of a correct response and the speed of that response. Although smaller in size, a significant effect was also observed in Speech Rate, in the by-participants analysis at least. The trend towards an advantage for concrete over abstract words in Repetition was not significant. No significant concreteness effects were observed on Word Identification in Noise or Lexical Decision.

4.3.4 Analysis of Relationships between Language Processing Measures and Immediate Serial Recall

The data were entered into a 'Method 3' regression analysis (Lorch & Myers, 1990), a form of analysis that considers item variance, within individual participants. Each participant's raw score on each item in each task is entered, with the aim of examining how their performance on a word in one task predicts performance on that word in other measures. A simultaneous linear regression was performed using this method. Auditory Lexical Decision, Word Identification in Noise, Definition Naming (correct responses), Delayed Repetition (mean reaction time after 1 and 3 second delays), Speech Rate (time for ten repetitions of word), and item length (in ms) were entered into the analysis, with ISR performance as the dependent variable. The results are displayed in Table 4.3.

Variable	t	Unique R_2	Sig t
Item Length	-4.622	.007	.0000
Auditory Lexical Decision	-1.169	.000	.2424
Word Identification in Noise	-.985	.000	.3247
Definition Naming (Correct)	1.579	.001	.1144
Repetition	1.327	.001	.1846
Speech Rate	-.249	.000	.8036

Table 4.3. Within-participant item regression analysis with Serial Recall performance as the dependent variable

It can be seen from Table 4.3 that, in this experiment, performance in none of the tasks predicts unique variance in word recall. The ease with which a participant is able to perceive and recognise an aurally presented word does not predict how well they can remember a word in Immediate Serial Recall. Similarly, a participant's production of a word (as measured by three different tasks) is not related to their recall of that word. The only factor to predict memory performance was item length, in that the longer a word's sound-file was (as spoken for presentation in the experiment), the less likely a participant was to recall it.

In order to examine further the relationship between Definition Naming performance and verbal short-term memory, a second regression analysis was performed, using Definition Naming reaction times instead of correct responses. The focus of the study meant that only reaction times for correct responses were of interest. Therefore, this analysis was performed on the words that participants correctly named to definition (approximately 61% of the data). Aside from the change in Definition Naming measurement, this regression was identical to the analysis described previously. The results are displayed in Table 4.4.

Variable	t	Unique R_2	Sig t
Item Length	-2.418	.005	.0158
Auditory Lexical Decision	.658	.000	.5106
Word Identification in Noise	.573	.000	.5665
Definition Naming (RT)	-2.649	.006	.0082
Repetition	.157	.000	.8749
Speech Rate	-.176	.000	.8602

Table 4.4. Within-participant item regression analysis on items named correctly to definition, with Serial Recall as the dependent variable

Using a different measure of Definition Naming (speed of correct response production), performance on this task does now predict unique variance in Immediate Serial Recall. When participants were able to name a word to it's definition, the quicker they were able to do this, the greater the likelihood of recalling that word in the short-term memory task. In line with the previous regression, neither the two input tasks, nor Repetition or Speech Rate predict unique variance in Immediate Serial Recall performance, whereas spoken item length again does.

4.4 Discussion

The experiment reported in this chapter featured multiple measures of language processing, using a large item set in which rated concreteness was the manipulated variable. Significant concreteness effects were again observed in Immediate Serial Recall. This variable also had a large influence on both the rate and reaction time of correct responses in Definition Naming. A smaller concreteness effect, significant in the participants analysis, was also observed in Speech Rate. Although a small trend towards an advantage for concrete over abstract words was apparent in Repetition, this was not significant. No significant effects were found in Auditory Lexical Decision or Word ID in Noise. Regression analyses revealed that the only significant predictors of unique variance in Serial Recall were Definition Naming reaction times and spoken item length. Performance in none of the other tasks predicted short-term memory.

These findings add to growing evidence of an influential involvement for semantic processing in verbal short-term memory. In line with Experiments One, Two, and Three, a substantial and significant advantage for concrete over abstract words was observed. This may reflect the role of temporary semantic coding and the process of semantic redintegration as described by Walker and Hulme (1999). Alternatively, this semantic coding may be a temporarily activated part of long-term memory, serving to support the temporary storage and production of phonological information. Language-based memory models that propose multiple linguistic coding capacities (e.g. Monsell, 1984, 1987; R.Martin et al., 1999) are nevertheless supported.

It is useful to further examine the patterns of Serial Recall performance. A significant concreteness x serial position interaction was found, reflecting the decreased concrete advantage at the final list position. This contrasts with a lack of interaction in Experiments One and Three and in Walker and Hulme (1999), and a completely opposite interaction (an effect only at later list positions) in Experiment Two (on children). This would suggest concreteness x position interactions, significant or otherwise, to merely be the result of variations between participant samples, word sets, and list lengths.

Another somewhat inconsistent pattern in the four experiments involving concreteness relates to the significant effect of this variable that was observed on order error rates. This is in line with Experiment One, but not the second or third experiments. As argued in Chapter Two, this finding does not necessarily suggest the semantic system to have a direct influence on memory for order. Instead, the increased likelihood of item errors on abstract words would impair the ordered recall of subsequent items in the list. This could occur through disruption to the retrieval process, or as a result of the extra cognitive demands placed on the system by the retrieval of degraded abstract materials. Concreteness would then influence order error rates without influencing order coding itself. For a more detailed explanation, see earlier chapters.

A much more consistent pattern of results is evident for item errors. The significant effect of concreteness on item errors overall, and specifically omission errors and phonological approximation errors, represents an exact replication of the findings in the first three experiments. It appears that semantic information primarily serves to enable accurate storage and retrieval of item information, with the less active and reliable support from abstract words resulting in a greater likelihood of complete information loss (an omission) and the production of a phonologically similar but incorrect response. The increased rates of phonological approximation errors on abstract words reported in the four concreteness experiments are consistent with the memory and speech production response patterns of patients with impairments in semantic support for phonological processing (e.g. Knott et al., 2000; R. Martin et al., 1999; Patterson, Graham, & Hodges, 1994).

The failure to observe a significant concreteness effect in Auditory Lexical Decision represents a replication of the findings from Experiment Three, and a further refutation of previous research reporting a substantial effect of this variable on ALD performance. As noted in Chapter Three, this apparent contradiction with findings in the literature may be due to uncontrolled differences in spoken item length. In this experiment, a concreteness effect on raw reaction times of around 47ms was apparent. However, the sound-files of abstract words were, on average, 55 ms longer than the concrete item sound-files. The concreteness effect was therefore abolished when reaction time from item offset was used as the measure of performance.

These results, coupled with the findings in Experiment One and Experiment Three, would appear to suggest that the influence of word concreteness on processing in the input pathway is relatively small and task-specific. This is further supported by the finding that performance in Word Identification in Noise, a task in which large semantic ambiguity and related sense effects emerged in Experiment Four, was not significantly influenced by concreteness. It appears that any increased semantic feedback for concrete words did not benefit the processing of degraded auditory stimuli. These results add weight to the idea that the different semantic profiles of concrete and abstract words have little influence on most measures of word recognition. They also indicate that word concreteness and related senses are represented differently in the semantic system, countering the claims of Rodd et al. (2002), as an equivalent theoretical basis would be predicted to lead to equivalent empirical findings.

An alternative explanation can be derived from the observation made by Plaut (1997), that a Lexical Decision response can be based on various aspects of the stimuli, and that semantic processing is not necessary for successful performance. This account may also extend to Word Identification in Noise so that, on the items used in this experiment (and Experiment Three), participants did not require semantic information when performing these tasks. In contrast, this information was important in attempting to remember the same items in Serial Recall.

The large concreteness effects on Definition Naming correct rates uncovered in previous experiments were replicated in the present study, as predicted by speech production models (e.g. Dell, 1986; Dell et al., 1997; Levelt et al., 1999). It appears that this variable has a considerable effect on aspects of the output pathway measured by Definition Naming. The concreteness effect also extends to reaction times with an advantage of around 900 ms for concrete words, a very large effect size in the context of reaction time data. Phonological forms of concrete words are accessed and produced both faster and more accurately, possibly due to high levels of activation being conveyed from semantic representations to output phonology.

The size of the effect on Definition Naming can be particularly understood when compared with the Delayed Repetition data, in which the largest difference between item sets was 6 ms (for Repetition 3). This is again equivalent to the small effects of imageability (between 7-8ms) observed by de Groot (1989) in visual naming. A replication of the Repetition data from Experiment Three was observed, in that a very small and non-significant trend towards a concreteness effect emerged. As noted in Chapter Three, participants are able to repeat simple words without the requirement for support from semantic processing (e.g. Strain et al., 1995), through the use of the non-semantic input phonology to output phonology route. This would preclude substantial semantic effects from emerging, as other factors such as ease of articulation become more important. As argued by Strain et al., it may be that semantic effects only emerge in normal repetition and naming performance when required as support for phonological processing.

This notion of a pervasive influence of semantics on the speech output system that only emerges when support is required for phonology is more in line with restrained spreading activation models of production (e.g. Dell et al., 1997), than serial feed-forward models such as WEAVER++ (Levelt et al., 1999). Support for this approach comes from the observation of a significant effect (in the participant analysis) on Speech Rate, again replicating the findings from Experiment Three. The argument put forward in Chapter Three, that concreteness effects on Speech Rate are more likely to emerge with a larger item set, is therefore upheld. As suggested earlier, concreteness effects may emerge in Speech Rate (and to an extent in Immediate Serial Recall) through semantic support ensuring that output phonology representations and articulatory programs remain active and well defined.

An increasingly clear picture is emerging concerning the influence of concreteness on speech processing and the possible basis of this effect in Immediate Serial Recall. This experiment represents a culmination, replication, and extension of previous experiments, and suggests the influence of this semantic variable in short-term memory to arise primarily through the underlying operation of speech output processing. Specifically, the relative magnitude and robust nature of the effect on two measures of

Definition Naming suggest the processes critical to this task to be the potential main source of concreteness effects in short-term memory. This does not rule out the possibility that processing further down the output pathway also makes a contribution to Serial Recall concreteness effects, as indicated by the small word set effects on these tasks. Nevertheless, it can be argued that concreteness effects in verbal memory may emerge for the most part during interactions between meaning and output phonology.

This in turn would indicate the mechanisms and representations underlying Definition Naming to have an influential role in verbal short-term memory. Evidence for this can be derived from the results of the Lorch and Myers (1990) regression analyses. The use of multiple language measures in this experiment enabled the relative importance of many aspects of speech processing to be assessed together, in a single analysis. The first of the two analyses revealed that item length was the only predictor of unique variance in Serial Recall, in that the shorter the item stimuli was, the better it was recalled by each participant. In line with previous experiments, neither of the two input tasks were related to short-term memory. In addition, the production measures were similarly unconnected to memory performance. The failure of Definition Naming (correct rates) to predict short-term memory contrasts with the first two experiments.

The second analysis, performed only on the items that each participant correctly named to definition, revealed spoken item length and Definition Naming (reaction time) to be significant predictors of Serial Recall variance. In other words, the faster a participant was at correctly naming a word to its definition, the better their memory performance was on that word. This link between Definition Naming and Serial Recall performance again indicates that the mechanisms within the speech output pathway that are critical to the former may also be important to the latter.

As performance in the other language measures did not predict short-term memory in either analysis, it can be inferred that the processing capacities important to these tasks are relatively less influential in Serial Recall. Under a language-based approach such as the one outlined by Monsell (1984, 1987), these mechanisms would still be involved in verbal short-term memory, but would be comparatively less crucial to the storage and retrieval of linguistic information. Overall, the finding that Serial Recall performance is only predicted by performance in a speech production task replicates the majority of results reported in previous chapters, and further implicates the speech output pathway in verbal short-term memory.

Finally, it is worth noting that, as in Experiment One, spoken item length predicted variance in recall that was independent of Speech Rate or concreteness. Even though all items were one syllable in length, shorter stimuli were remembered better in Serial Recall. This may reflect the influence of phonological complexity on performance (Caplan et al., 1992; Service, 1998, 2000) and/or output interference (Cowan et al., 1992) and stimulus duration (Cowan et al., 2000) on short-term memory. It may be that words that take longer to produce, possibly as a result of their phonological complexity, are recalled less well.

5.5 Chapter Summary

The experiment reported in this chapter constituted a culmination of previous experimental work, with a large item set used in multiple measures of language processing. Large concreteness effects were observed in Immediate Serial Recall and two measures of Definition Naming performance. Smaller but significant effects were also found in Speech Rate. In contrast, no significant influence of this variable was observed in Auditory Lexical Decision, Word Identification in Noise, or Delayed Repetition. A regression analysis revealed that the only predictors to account for unique variance in participants' short-term memory performance were stimuli length and reaction times for correct responses in Definition Naming. The two word recognition tasks and the three other measures of production (including Definition Naming correct rate) were not significantly related to Serial Recall performance in this experiment.

These results represent a replication and extension of previous findings, providing a detailed picture of verbal short-term memory and language processing within a single experiment. An influence of semantic processing has emerged that persists throughout speech production, and varies in magnitude according to the semantic load of the task. In turn, this would suggest concreteness effects in Serial Recall to arise through the involvement of output processing, particularly interactions between semantic representations and output phonology (as measured by Definition Naming). These findings, coupled with the results of the regression analyses, indicate that speech production mechanisms are relatively more important than speech input mechanisms for temporary verbal memory processes.

Chapter Five

Lexical Phonology in Speech Processing and Verbal Short-Term Memory

Verbal short-term memory as measured by Immediate Serial Recall appears to be heavily reliant on language processing mechanisms and representational capacities. Specifically, it has been established in previous chapters that semantic processing is important to temporary verbal storage and retrieval. The semantic effects that have emerged in short-term memory tasks may reflect the temporary activation of conceptual representations and the influence of this activation on other aspects of the speech processing system. Furthermore, the relative magnitude and task-specificity of these effects on various language measures have indicated representational capacities within the speech output pathway to be more influential in verbal memory processing. Regression analyses have provided evidence for such claims, with production task performance predicting recall variance at an individual item, within-participant level.

As illustrated in Figure 1.4, separable speech input and output pathways are thought to be served by a unitary semantic system. When manipulating word meaning, the relative importance of perception and production in STM is reflected through the interactions between input phonology and semantics, and semantics and output phonology. The temporary coding of word meaning may not in itself be separable between input and output.

In contrast, distinct lexical phonological representations may exist for the processing of word recognition and speech production. Monsell (1984, 1987) outlined such an approach, and claimed that both input and output phonology are responsible for phonological short-term memory. An examination of how phonology is processed in short-term memory would provide interesting indications as to the potential relative roles of speech input and output processing. It may be that temporary coding within one of the phonology lexicons is more critical to short-term memory than the other. For example, some models have attributed a greater importance to input phonology (e.g. Burgess & Hitch, 1999; Gathercole & Martin, 1996).

In this chapter, the role of speech processing is examined in the emergence of lexical phonological effects that have recently been observed in short-term memory. This in turn would provide further insight as to the relationship between temporary verbal storage and different aspects of the language processing system. If the claim were made that phonological representational capacities within the language system form the basis of temporary phonological coding, similar effects would be expected in measures of memory and speech processing. Furthermore, regression analyses should produce complimentary results, with language task performance predicting Serial Recall. To examine these issues, another large-scale experiment was carried out, using the same multiple measures as those featured in Experiment Five. The two phonological variables manipulated were word frequency and neighbourhood size.

5 Effects of Word Frequency and Neighbourhood Size in Speech Input and Output Measures and Immediate Serial Recall

5.1 Introduction

As in Experiment Five, the input tasks used in this experiment were Auditory Lexical Decision and Word Identification in Noise. Speech production was measured through the use of timed Definition Naming, Delayed Repetition, and Speech Rate. Immediate Serial Recall was again the measure of verbal short-term memory. With the exception of Definition Naming, semantic processing may perform a supplementary role in the majority of these measures. In contrast, efficient and accurate phonological processing is of primary importance in every one of these tasks. Therefore, the first prediction was that substantial phonological effects would be observed in many of the language measures.

Word frequency has been shown to influence word recognition, production, and short-term memory. For example, frequency effects have previously been observed in Word Identification in Noise (Broadbent, 1967;

Howes, 1957; Luce, 1986; Owens, 1961; Rosenzweig & Postman, 1957; Savin, 1963) and Auditory Lexical Decision (Forster & Chambers, 1973; Marslen-Wilson, 1990; Slowiaczek & Pisoni, 1986; Taft & Hambley, 1986; Tyler et al., 2000; Whaley, 1978). Similarly, a processing advantage for high frequency words has been reported in picture naming (e.g. Bartram, 1974; Griffin & Bock, 1998; Humphreys, et al., 1988; Huttenlocher & Kubicek, 1983; Jescheniak & Levelt, 1994; Oldfield & Wingfield, 1965), word naming (e.g. Forster & Chambers, 1973; Lipchacz et al., 1999;), repetition (Tyler et al., 2000), and speech error production (Vitevitch, 2002). Consistent with a language-based memory approach (e.g. Monsell, 1984, 1987; R. Martin et al., 1999), beneficial frequency effects have also been observed in short-term memory (e.g. Hulme et al., 1997; Roodenrys et al., 1994; in press).

It appears that word frequency is a phonological variable with a pervasive influence on many measures of speech processing, including both perception and production. In particular, such effects are said to emerge at access to representations within input and output phonology (Griffin & Bock, 1998; Hino & Lupker, 1996; Jescheniak & Levelt, 1994). Frequency may influence Serial Recall through these processes, and so would possibly reflect the operation of both speech pathways in short-term memory. Beneficial effects of word frequency on the memory and language tasks were therefore predicted.

A variable of potentially greater interest was neighbourhood size. It has been observed that words from large phonological neighbourhoods (that is, with many similar sounding neighbours) are harder to recognise in Word Identification in Noise (Luce, 1986; Luce & Pisoni, 1998; Luce et al., 1990; Treisman, 1978) and Auditory Lexical Decision (Luce, 1986). Such inhibitory effects are thought to arise through competition between neighbours affecting the speed and accuracy of input processing (e.g. Luce & Pisoni, 1998; Marslen-Wilson & Zwitserlood, 1989; Norris, McQueen, & Cutler, 2000). A replication of these findings was predicted in this experiment.

In contrast, facilitatory effects of neighbourhood size and frequency have been consistently observed in visual word naming (Andrews, 1997). Gordon and Dell (2001) found similarly beneficial neighbourhood (and frequency) effects in behavioural measures and simulations of the speech production performance of aphasic patients, using the Dell et al. (1997) model. Vitevitch (2002) also observed an advantage for words from large neighbourhoods in error inducement paradigms and in picture naming. Vitevitch interpreted these findings using an interactive production framework, in which activation propagates between semantics, word-level lemmas, and output phonology, thus increasing the activation levels of the correct word nodes and phonological nodes. This process would result in greater activation for words from large neighbourhoods. Beneficial effects of neighbourhood size were therefore predicted on the three measures of speech production.

Any neighbourhood effects observed in short-term memory would therefore have important implications for language-based memory models. Several models, including Gupta and MacWhinney (1997), OSCAR, and redintegration, predict inhibitory effects on recall performance, and thus indicate input phonology to be more critical to short-term memory. If temporary retention of phonology were dependent upon processing within input phonology, it would follow that words from small neighbourhoods would be easier to remember in immediate verbal memory. However, Roodenrys et al. (in press) have recently observed facilitatory effects of word frequency, neighbourhood size, and neighbourhood frequency on memory span and Immediate Serial Recall. This would appear to refute a central role for input phonology in short-term memory, and instead suggest the output pathway to be critical to immediate memory performance.

A confident interpretation of these various findings is problematic however, as different studies will inevitably involve different participants, item sets, and auditory stimuli. Therefore, this experiment was intended to examine the influence of word frequency and neighbourhood size on word recognition, speech production, and verbal short-term memory, using the same participants and experimental item set in each task. The words featured in this experiment were taken from Roodenrys et al. (in press, Experiment One). If the experimental findings recently reported in the perception, production, and memory literature were replicated in a single study, this would provide strong evidence for an output-centric model of short-term memory. In contrast, if the predictions of several of the memory models were supported, and inhibitory effects of neighbourhood size emerged, this would suggest input phonology to be more influential in STM.

In addition, the experimental design again enabled a large-scale regression analysis to be performed on individual participant and item data. This was expected to compliment the results from previous experiments and/or the pattern of variable effects observed in this study, in identifying the primary links between memory and language performance.

5.2 Method

5.2.1 Participants

Thirty University of York undergraduates and postgraduates took part, receiving course credit or payment for their participation. There were 8 men and 22 women, with an age range of 19-26 years.

5.2.2 Materials

Items were taken from Roodenrys et al. (in press, Experiment 1). The experimental set comprised four sets of 16 words, with word frequency and neighbourhood size the manipulated variables. All words in the two high-frequency sets (HF) had a frequency greater than 50 words per million (Kucera & Francis, 1967), while low-frequency sets (LF) contained words with a frequency of 6 words per million or less.

The large neighbourhood size sets (LN) contained words with 18 or more neighbours, while words in the small neighbourhood sets (SN) had a maximum of 14 neighbours. All items had a CVC (consonant-vowel-consonant) structure, and were three phonemes in length. Phonological similarity was minimised within each item set, and was controlled along with neighbourhood frequency, across conditions. The experimental items and their values are provided in Appendix H.

Definitions for these words were selected from the Oxford and Collins English dictionaries, the Online Wordsmyth Educational Dictionary-Thesaurus and the WordNet online lexicographic database. Where more than one sense was available, the most frequent and semantically relevant definition was selected. A group of independent judges rated the accuracy and suitability of each definition, on a scale of 1-5. An analysis of variance revealed no significant differences in accuracy/suitability between the high- and low-frequency words (F (1,63) = 1.51, p = .223), or between the large and small neighbourhood words (F (1,63) = .168, p = .683). The definitions are provided in Appendix I.

For the Lexical Decision segment of the experiment, wordlike nonwords were created, by taking a real word and adding or removing one phoneme. The nonwords had a similar distribution of word lengths to the test stimuli. An English speaking person recorded the test and practice items, nonwords, and definitions onto a CD recorder. They were then transferred onto a Macintosh computer.

5.2.3 Procedure

The procedure followed in this experiment was very similar to that of Experiment Five. Each participant performed each task, with the same 64 items featured in each. The six tasks presented in the previous experiment were again administered, in the same order over three sessions. Therefore, participants performed Auditory Lexical Decision and word identification in noise in the first session, Definition Naming and Delayed Repetition in the second session, and Immediate Serial Recall and Speech Rate in the final session. Alterations of tasks for the purposes of this experiment were minimised and were, for the most part, due to the use of a slightly smaller item set than the one featured in the previous experiment (64 as opposed to 68 items). For a more detailed description of the tasks, see previous chapters.

Auditory Lexical Decision (ALD) Twenty practice items preceded the test phase, which consisted of 64 words and 64 nonwords presented to the participant in random order.

Word Identification in Noise (WIN) To ensure an even distribution of scores across the four presentation rounds, the second of the rounds featured a sound-noise attenuation level of –9 dB signal-to-noise ratio (as opposed to –8 dB used in previous experiments). All other settings were identical to those previously used.

Immediate Serial Recall (ISR) Each of the four word sets was presented in their own 16 list series, with seven items in each list.

5.3 Results

5.3.1 Summary of Task Performance

The participant means for each task are displayed in Table 5.1. An interesting pattern of results is apparent. Performance in each task does appear to vary as a function of both frequency and neighbourhood size. Auditory Lexical Decision times are faster for high- than low-frequency words. In addition, quicker reaction times are apparent for words from small than large neighbourhoods. A similar pattern of improved performance on high-frequency words and small neighbourhood words can also be observed in the second input task, word identification in noise. The exception to this is on high-frequency words, where little difference in performance is apparent between large and small neighbourhood sets.

Word Sets*	HFLN	HFSN	LFLN	LFSN
Serial Recall (%)	59.26 (13.64)	53.24 (10.51)	52.44 (10.75)	47.38 (13.72)
ALDT (ms)	326.20 (101.38)	302.47 (88.44)	389.59 (105.46)	323.47 (102.45)
WIN (mean round ID)	2.47 (.36)	2.50 (.37)	3.23 (.46)	2.99 (.31)
Definition Naming				
% Correct	82.08 (9.25)	80.42 (11.69)	64.17 (13.42)	51.46 (15.63)
RT (ms)	826.27 (357.78)	1044.18 (462.63)	1212.31 (754.78)	1479.84 (1000.16)
Delayed Repetition				
1 sec delay	441.35 (71.34)	466.29 (78.67)	460.83 (83.90)	453.11 (74.82)
3 sec delay	388.64 (65.98)	405.94 (68.18)	394.94 (68.71)	398.58 (71.98)
Total (mean)	415.00 (49.04)	435.69 (55.25)	427.88 (58.13)	425.84 (55.41)
Speech Rate (w/s)	3.24 (.61)	3.05 (.56)	3.11 (.58)	3.02 (.54)

Table 5.1. Means (and standard deviations) for performance on speech processing tasks for each word set

*HFLN: High frequency, large neighbourhood.
LFLN: Low frequency, large neighbourhood.
HFSN: High frequency, small neighbourhood.
LFSN: Low frequency, small neighbourhood.

The beneficial effect of word frequency on performance also extends to both measures of Definition Naming. Participants were able to correctly name more high frequency than low frequency words to their definitions, and when they did so, they produced their responses quicker. A small frequency advantage is also apparent in Speech Rate. However, while frequency appeared to benefit Repetition of words from large neighbourhoods, a negative frequency effect is apparent on items from small neighbourhoods.

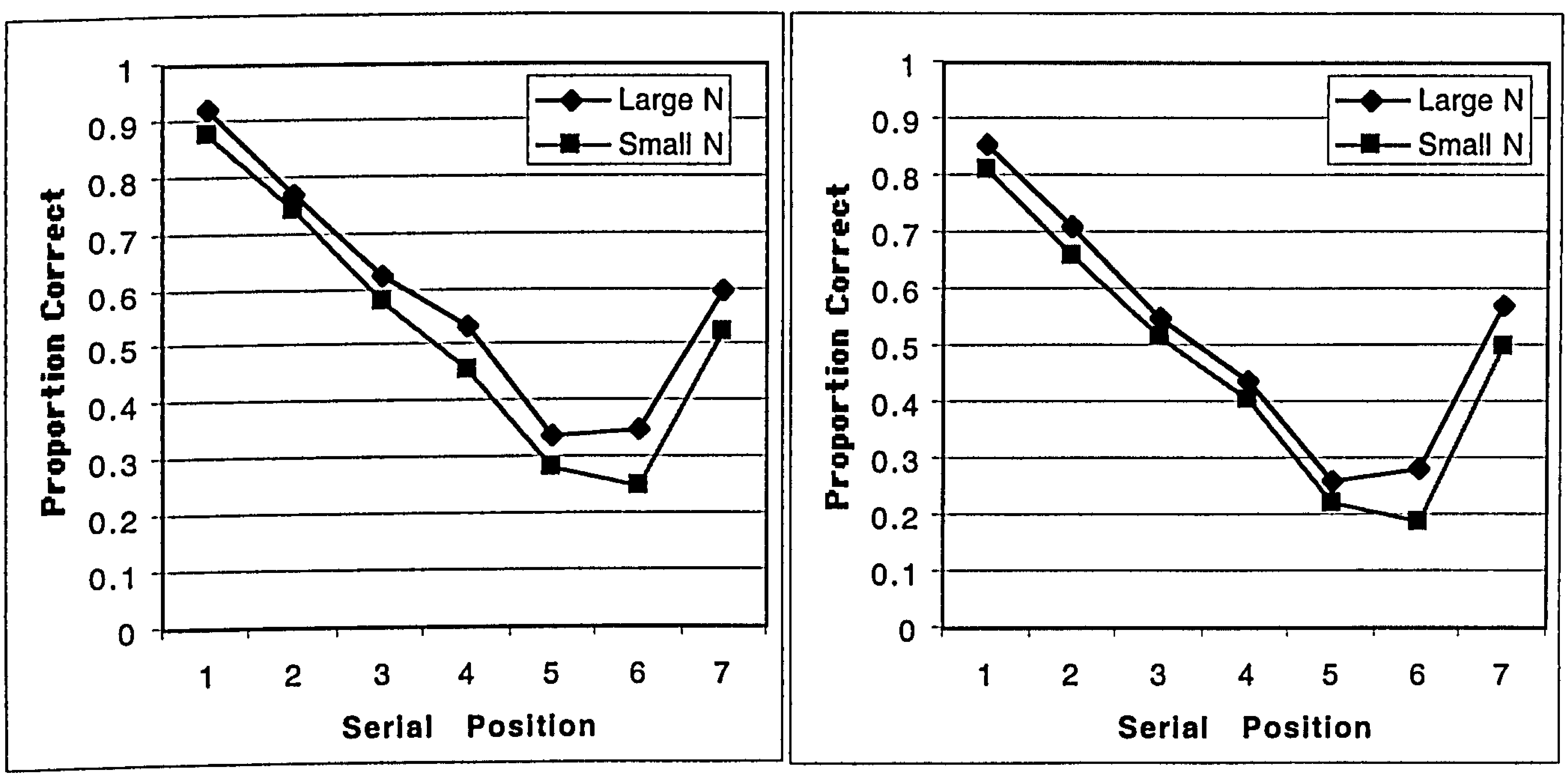
In contrast to the inhibitory effect of neighbourhood size that emerged in the two speech input tasks, beneficial effects of this variable are apparent on all measures of production in this experiment. Participants were more likely and quicker to name a word to its definition, were quicker at repeating a word once to a cue (on the high frequency sets, at least), and could rapidly repeat a word at a quicker rate, if it was from a large phonological neighbourhood.

Finally, similar results are apparent in Immediate Serial Recall. Beneficial effects of word frequency and neighbourhood size are can be seen in Table 5.1, and are illustrated as a function of serial position in Figures 5.1 and 5.2.

5.3.2 Immediate Serial Recall

Figure 5.1 shows bowed serial position curves for the four item sets, with large primacy effects and smaller recency effects. A generally lower proportion of correct responses for low frequency and small neighbourhood items relative to high frequency and large neighbourhood words is apparent at all serial positions.

The data were entered into a 2x2x7 repeated measures ANOVA, with frequency, neighbourhood size, and serial position as the variables. This revealed significant main effects of frequency (F (1,29) = 37.80, p < .001), neighbourhood size (F (1,29) = 20.83, p < .001), and serial position (F (6,174) = 143.24, p < .001) on recall. The interactions between frequency and neighbourhood size (F (1,29) = .16, p = .691), frequency and position (F (6,174) = .68, p = .668), and neighbourhood size and position (F (6,174) = 1.21, p = .304) were not significant, nor was the three-way interaction (F (6,174) = .27, p = .950).



High Frequency Words **Low Frequency Words**

Figure 5.1. Recall of high- and low-frequency words as a function of neighbourhood size and serial position

It is apparent that participants made more errors on lists of low-frequency words and words from small neighbourhoods. In order to examine this in more detail, response types were categorised using the classification system featured in previous experiments. The results are displayed in Table 5.2, as proportions of the total number of responses for each item set.

		Errors						
			Item Errors					
Word set	Correct	Order	Total Item	Omissions	ISI	IEI	EEI	PA
HFLN	.593	.193	.215	.174	.032	.001	.002	.006
HFSN	.532	.198	.270	.204	.046	.012	.001	.006
LFLN	.524	.168	.307	.245	.033	.004	.001	.024
LFSN	.474	.194	.332	.271	.040	.007	.003	.010

Table 5.2. Response patterns in Serial Recall for each word set

The pattern of errors across the four item sets was examined in a series of ANOVAs. Firstly examining order error rates, it was necessary to calculate the proportion of order errors per item recalled. This produced a rate of .250 on HFLN items, .273 on HFSN, .245 on LFLN, and .297 on LFSN words. A 2x2 repeated measures ANOVA revealed a significant effect of neighbourhood size on order errors per item recalled (F (1,29) = 11.23, p < .01). However, the effect of frequency was not significant (F (1,29) = .99, p = .329), nor was the frequency x neighbourhood size interaction (F (1,29) = 1.54, p = .224).

A 2x2 repeated measures ANOVA examining the overall proportion of item errors revealed significant effects of frequency (F (1,29) = 58.76, p < .001) and neighbourhood size (F (1,29) = 15.07, p < .01). The frequency x neighbourhood size interaction was also significant (F (1,29) = 4.22, p < .05), possibly reflecting the larger effect of neighbourhood size on item errors for high frequency words. A series of repeated measures analyses were also performed on the item error subtypes. Analysis of omission error rates revealed significant effects of frequency (F (1,29) = 41.77, p < .001) and neighbourhood size (F (1,29) = 11.35, p < .01), but no interaction (F (1,29) = .12, p = .731). Examining intra-set intrusion errors, there were no effects of frequency (F (1,29) = .52, p = .476), neighbourhood (F (1,29) = 2.77, p = .107), or the interaction (F (1,29) = .68, p = .416). There was a significant effect of neighbourhood size on intra-experiment intrusions (F (1,29) = 6.37, p < .05), although the influence of frequency (F (1,29) = .06, p = .813) and the neighbourhood size x frequency interaction (F (1,29) = 1.39, p = .248) were not significant. Finally, an analysis of phonological approximation error rates revealed significant effects of frequency (F (1,29) = 16.54, p < .001) and neighbourhood size (F (1,29) = 7.11, p < .05). The interaction was also significant (F (1,29) = 7.97, p < .01). This reflects the increased rate of PA errors on low frequency, large neighbourhood items.

Although word frequency and neighbourhood size both had similar positive effects on Immediate Serial Recall performance, their influence on the pattern of error rates was not equivalent. Frequency effects emerged through differences in item errors, specifically with larger proportions of omissions and phonological approximation errors on low-frequency words. However, neighbourhood size significantly influenced the rate of order errors as well as item errors. The larger proportion of item errors on small neighbourhood words was due to increased omission and intra-experiment intrusion rates. In contrast to the effect of frequency on PA errors (and the overall positive effect of neighbourhood size on performance), the proportion of approximation errors was increased on words from large neighbourhoods, specifically on low frequency items.

It is apparent that neighbourhood size and frequency have robust positive effects on Serial Recall performance. The influence of these variables on performance in the word recognition and production tasks will now be examined.

5.3.3 Analysis of Performance on the Language Tasks

Auditory Lexical Decision

A 2x2 repeated measures ANOVA was performed on the Auditory Lexical Decision response times (as measured from spoken item offset). This revealed a significant beneficial effect of frequency (F (1,29) = 30.78, $p < .001$), and a significant inhibitory effect of neighbourhood size (F (1,29) = 29.44, $p < .001$). In addition, the frequency x neighbourhood size interaction was significant (F (1,29) = 9.85, $p < .01$), reflecting the larger influence of neighbourhood size on responses to low frequency items.

In addition, a, by-items analysis of variance was carried out on the Lexical Decision data. This revealed significant effects of frequency (F (1,63) = 11.46, $p < .01$) and neighbourhood size (F (1,63) = 9.27, $p < .01$), on the speed to which an item was responded, relative to its offset. The interaction was not significant in the by item analysis (F (1,63) = 1.11, $p = .296$).

The error rate on this task was low, with around 7% of test items inaccurately responded to as being nonwords. To divide errors on the basis of item sets, 1.04% of responses to HFLN words were incorrect, 2.29% were incorrect for HFSN words, 13.13% on LFLN words, and 11.46% of responses to LFSN words were incorrect. A repeated measures ANOVA produced a significant effect of frequency on error rates (F (1,29) = 110.84, $p < .001$). However, the effects of neighbourhood size (F (1,29) = .10, $p = .756$) and the frequency x neighbourhood size interaction (F (1,29) = 2.67, $p = .113$) were not significant. Similarly, a by-item ANOVA revealed the effect of frequency to be significant (F (1,63) = 10.21, $p < .01$), although neighbourhood size (F (1,63) = .004, $p = .950$) and the interaction (F (1,63) = .192, $p = .663$) were again not significant.

Word Identification in Noise

The 2x2 repeated measures ANOVA revealed a significant beneficial effect of frequency (F (1,29) = 159.79, $p < .001$), and a significant inhibitory effect of neighbourhood size (F (1,29) = 4.38, $p < .05$). The interaction was also significant (F (1,29) = 6.48, $p < .05$), again due to the larger neighbourhood size effect for low frequency items.

The effect of frequency on was also significant in the by item analysis of variance (F (1,63) = 7.78, $p < .01$). However, the neighbourhood effect was not significant in this analysis (F (1,63) = .205 $p = .652$), nor was the frequency x neighbourhood size interaction (F (1,63) = .352, $p = .555$).

Definition Naming

Two measures of Definition Naming performance will be reported in this experiment, these being rate of correct responses and correct response reaction times. It is important to note that the RT measure only involves around 70% of the possible data (i.e. the times for correct responses only).

A within-participants analysis of variance on correct response rates in Definition Naming revealed significant effects of frequency (F (1,29) = 147.62, p < 001) and neighbourhood size (F (1,29) = 18.54, p < 001). The interaction was also significant (F (1,29) = 7.12, p < 05). Similarly, significant effects of frequency (F (1,29) = 20.33, p < 001) and neighbourhood size (F (1,29) = 8.25, p < 01) were also observed on the reaction times for correct responses. The frequency x neighbourhood size interaction was not significant (F (1,29) = .08, p =. 786).

In the by-item analysis of variance, a significant effect of frequency on correct response rates was observed (F (1,63) = 13.20, p < 01). However, the effect of neighbourhood size was not significant in this analysis (F (1,63) = 1.24, p = 270), nor was the frequency x neighbourhood size interaction (F (1,63) = .732, p = 396). Similarly, a significant effect of frequency was found on Definition Naming reaction times (F (1,63) = 10.52, p < 01), while the neighbourhood size effect was again not significant in the items analysis (F (1,63) = .467, p = .497). The frequency x neighbourhood size interaction was not significant (F (1,63) = .024, p = .878).

Delayed Repetition

A 2x2x2 repeated measures ANOVA was performed, with frequency, neighbourhood size, and delay length as the factors. The frequency effect was not significant (F (1,29) = .44, p = .510). However, both neighbourhood size (F (1,29) = 16.06, p < .001) and delay length (F (1,29) = 97.63, p < .001) had significant effects on performance. The frequency x neighbourhood size interaction was also significant (F (1,29) = 18.64, p < .001). The frequency x delay (F (1,29) = .52, p = .475), neighbourhood size x delay (F (1,29) = .12, p = .737), and three-way interactions (F (1,29) = 3.05, p = .091) were not significant.

A by-item ANOVA revealed a significant effect of delay (F (1,127) = 127.93, p < .001). However, the effects of frequency (F (1,127) = .047, p = .828) and neighbourhood size (F (1,127) = 3.31, p = .071) were not significant in this analysis, although the frequency x neighbourhood size interaction was (F (1,127) = 4.91, p < .05). The frequency x delay (F (1,127) = .046, p = .830), neighbourhood size x delay (F (1,127) = .008, p = .930), and three-way interactions (F (1,127) = 889, p = .348) were not significant.

Speech Rate

Analyses of variance were also carried out on the Speech Rate data. The 2x2 repeated measures participants analysis revealed significant effects of frequency (F (1,29) = 38.67, p < .001) and neighbourhood size (F (1,29) = 62.36, p < .001) on Speech Rate performance. In addition, the frequency x neighbourhood size interaction was significant (F (1,29) = 15.88, p < .001).

In the by-item analysis, the frequency effect was not significant (F (1,63) = 1.69, p = .198). In contrast, the neighbourhood size effect was significant in this analysis (F (1,63) = 4.60, p < .05). The frequency x neighbourhood size interaction was not significant (F (1,63) = .215, p = .645).

To summarise the results of these analyses, it is apparent that word frequency and neighbourhood size have robust positive effects on performance in the Immediate Serial Recall task, for both participants and items. Similarly, significant effects of both these variables were observed on

Definition Naming (error rates and reaction times) and Speech Rate. The neighbourhood effect also emerged on high frequency words in Delayed Repetition, although there were no frequency effects in this third measure of production. In contrast, although positive frequency effects were observed on the two speech input measures, neighbourhood size had a significant inhibitory influence on performance in Auditory Lexical Decision and word identification in noise.

5.3.4 Analysis of Relationships between Language Processing Measures and Immediate Serial Recall

The data were then entered into what has been termed a 'Method 3' regression analysis (Lorch & Myers, 1990), a form of analysis that considers item variance, within individual participants. Each participant's raw score on each item in each task is entered, with the aim of examining how their performance on a word in one task predicts performance on that word in other measures. A simultaneous linear regression was performed using this method. Auditory Lexical Decision, Word Identification in Noise, Definition Naming (correct responses), Delayed Repetition (mean reaction time after 1 and 3 second delays), Speech Rate (time for ten repetitions of word), and item length (in ms) were entered into the analysis, with Immediate Serial Recall performance as the dependent variable. The results are displayed in Table 5.3.

It can be seen from Table 5.3 that performance in neither of the input tasks predicts unique variance in word recall. The ease with which a participant is able to perceive and recognise an aurally presented word does not predict how well they can remember a word in Immediate Serial Recall. However, a participant's production of a word in response to its definition does predict their recall of that word. Item length also predicted short-term memory performance, in that the longer a word's sound-file was (as spoken for presentation in the experiment), the less likely a participant was to recall it. Neither Speech Rate nor Repetition predicted unique variance in recall performance.

Variable	t	Unique R2	Sig t
Item Length	-3.859	.006	.0001
Auditory Lexical Decision	.846	.000	.3976
Word Identification in Noise	-.1.519	.001	.1291
Definition Naming (Correct)	2.739	.003	.0062
Repetition	.750	.000	.4535
Speech Rate	-.025	.000	.9799

Table 5.3. Within-participant item regression analysis with Serial Recall as the dependent variable

In order to examine further the relationship between Definition Naming performance and verbal short-term memory, a second regression analysis was performed, using Definition Naming reaction times instead of correct responses. Therefore, this analysis was performed on the words that participants correctly named to definition (approximately 70% of the data). Aside from the change in Definition Naming measurement, this regression was identical to the analysis described previously. The results are displayed in Table 5.4.

	t	Unique R^2	Sig t
Item Length	-4.033	.010	.0001
Auditory Lexical Decision	.600	.000	.5488
Word Identification in Noise	-1.252	.001	.2109
Definition Naming (RT)	.611	.000	.5411
Repetition	.595	.000	.5522
Speech Rate	-.177	.000	.8599

Table 5.4. Within-participant item regression analysis on words named correctly to definition, with Serial Recall as the dependent variable

Using this second measure of Definition Naming (speed of correct response production), performance on this task does not predict unique variance in Immediate Serial Recall. This contrasts with the findings of Experiment Five. In line with the previous regression, neither the two input tasks, nor Repetition or Speech Rate predict unique variance in Immediate Serial Recall performance, whereas spoken item length again does.

Finally, in order to examine which of the factors in this experiment was most influential in short-term memory, a simultaneous regression analysis was performed on the recall data, with word frequency, neighbourhood size, neighbourhood frequency, and spoken item length as predictors. The results are displayed in Table 5.5.

	t	Unique R_2	Sig t
Word Frequency	6.438	.021	.0000
Neighbourhood Size	5.440	.015	.0000
Neighbourhood Frequency	2.662	.003	.0078
Item Length	-1.378	.001	.1683

Table 5.5. Regression analysis with variables as predictors of Serial Recall

The regression revealed that word frequency and neighbourhood size were the only variables to significantly predict unique variance in Serial Recall. The more frequent the item, and the more phonologically similar neighbours it has, the better it was recalled. Neither neighbourhood frequency or item length predicted recall variance.

5.4 Discussion

An interesting and complex pattern of results emerged in this experiment. Word frequency and neighbourhood size both had significant and positive effects on Immediate Serial Recall performance. Similarly beneficial effects of these variables were also observed on correct response rates and reaction times in Definition Naming, and also in Speech Rate. An advantage for words from large neighbourhoods was also observed in Delayed Repetition, although word frequency did not influence this task. In contrast, while frequency also had a facilitatory effect on Lexical Decision and word identification in noise performance, a negative influence of neighbourhood size emerged in these input tasks.

Within-participant regression analyses revealed that the only significant predictors of variance in Serial Recall were Definition Naming (correct response rate) and spoken item length. A further regression concerned with word variables revealed word frequency and neighbourhood size to be significant predictors of short-term memory. Neither neighbourhood frequency or item length predicted recall variance.

Recent short-term memory findings were replicated in the present study. An advantage for high- over low-frequency words was observed in Serial Recall, as reported by Roodenrys et al. (1994; in press) and Hulme et al. (1997). This would support the argument that stored language representations have an important role in verbal short-term memory, either through the operation of a phonological redintegration process (e.g. Hulme et al., 1997) or the involvement of these representations in information storage itself.

The absence of an interaction between word frequency and serial position contrasts with the findings of Hulme et al. (1997). They argued that a larger frequency effect at later serial positions reflects an increased demand for redintegration due to output interference, with high-frequency words undergoing a more efficient trace restoration process. However, the independent effects of serial position and frequency in the present experiment refute this argument somewhat.

As reported by Roodenrys et al. (in press), the proportion of order errors per item recalled was increased on low-frequency words. This again appears to suggest that stored language knowledge influences order as well as item memory. The explanation applied to similar findings with concreteness can again be used, as item errors earlier in a list increase the probability of order errors on subsequent items. More omission and phonological approximation errors were made on lists of low-frequency words, replicating the Roodenrys et al. results. This would support the idea that the presence of active and well-defined lexical phonological representations (for high-frequency words) benefits item memory.

Importantly, the findings of Roodenrys et al. were further replicated, in that a significant advantage for words from large neighbourhoods was observed in Serial Recall. Using the items featured in Roodenrys et al. (Experiment One), a clearer set of results was actually observed, with neighbourhood effects emerging on both high- and low-frequency word sets. These findings are in direct contrast to the predictions made by many models of short-term memory (e.g. Gupta & MacWhinney, 1997; Brown et al., 2000).

A critical feature of such models is that words from large neighbourhoods will be under greater threat from intrusion by neighbours, resulting in incorrect retrieval of phonologically similar words. Examination of the error analysis actually provides some support for this, as phonological approximation errors were more common on lists of large neighbourhood (low frequency) words. However, this is a relatively small effect, and goes against a larger beneficial effect of neighbourhood size on overall performance. Many of the memory theories therefore appear to be without an adequate explanation for these results.

It is important to examine the findings from the speech processing measures, in order to assess the plausibility of language-based models of memory. In line with previous findings (e.g. Broadbent, 1967; Forster & Chambers, 1973; Howes, 1957; Luce, 1986; Owens, 1961; Savin, 1963; Slowiaczek & Pisoni, 1986; Taft & Hambley, 1986; Whaley, 1978), beneficial word frequency effects were observed in Lexical Decision and word identification in noise. It appears that the active and well-defined representations of frequent words in input phonology enables faster and more accurate word recognition processing. This would suggest input phonology to have an influential role in Serial Recall, and to be a major underlying source of the frequency effect in that measure.

However, the observation of adverse neighbourhood size effects in both recognition tasks refutes this possibility. If phonological processing within the input pathway were central to Serial Recall storage and retrieval, equivalent (and not opposite) findings would be predicted using the same words in word recognition and short-term memory. The advantage for words from small phonological neighbourhoods that was found in Lexical Decision and Word Identification in Noise represents a replication of previous research (Luce, 1986; Luce & Pisoni, 1998; Luce et al., 1990; Treisman, 1978).

Word recognition models (e.g. Luce & Pisoni, 1998; Marslen-Wilson & Zwitserlood, 1989; Norris et al., 2000) propose that, when words from large neighbourhoods are processed within the input pathway, increased competition occurs between phonological representations. This adversely affects the speed and accuracy of input processing, leading to the effects observed in the recognition measures in this experiment. When compared with the findings uncovered in Serial Recall, it appears unlikely that phonological perception mechanisms have a central and influential role in verbal short-term memory.

Roodenrys et al. (in press) suggested that speech production processes may instead be responsible for the beneficial neighbourhood effects they reported in memory span and Serial Recall. The similar influence of this variable on short-term memory and three measures of word production in this experiment provide support for this claim. Significant neighbourhood size effects were observed on both correct rates and reaction times in Definition Naming, a pattern of findings equivalent to those recently observed by Vitevitch (2002) in picture naming. Similarly, the effects in Repetition are analogous to similar findings in visual naming (e.g. Andrews, 1997), while Roodenrys et al. (in press) also reported neighbourhood effects in Speech Rate.

Vitevitch (2002) and Gordon & Dell (2001) have claimed that the feed-forward and feedback of activation between semantics, lemma nodes, and output phonology results in a neighbourhood size advantage in output tasks. After initial semantic processing, the phoneme nodes of the target item are increasingly activated and reinforced by their own semantic and lemma nodes, and those of phonological neighbours, through spreading activation between and within representational levels. This explanation can easily be applied to Definition Naming. Also, the relatively highly activated phonological representations of words from large neighbourhoods would enable rapid and accurate word articulation, as tapped by Repetition and Speech Rate.

This process of spreading activation (as described in interactive models of production) may underlie neighbourhood effects in immediate memory tasks. Target word phonology would feed activation back to, and consequently receive activation from, target word semantic representations and the semantic representations of phonological neighbours. This interaction between representational levels within the output pathway would ensure continuing activation of temporary phonological coding, resulting in improved overall memory performance. The activation of phonological neighbours would also lead to the increased rate of approximation errors, as participants incorrectly recall a neighbouring item.

Substantial word frequency effects were also observed in Definition Naming and Speech Rate, replicating previous findings (e.g. Griffin & Bock, 1998; Hulme et al., 1997; Jescheniak & Levelt, 1994). As previously argued, the frequency advantage is thought to arise during access to phonological representations. The highly active representations of high-frequency words in output phonology would be easier to access from semantic and word-level processing in Definition Naming, and would provide increased support for repeated articulation in Speech Rate.

However, the predicted frequency effect was not observed in Delayed Repetition. Word frequency is a variable that generally influences any task sensitive to phonological access processing. While it appears to be affected by activation from output phonology (as evidenced by neighbourhood effects) it is possible that Delayed Repetition does not crucially depend upon access to phonological representations. As observed by Forster and Chambers (1973), frequency effects do not consistently arise in tasks measuring the execution of articulatory movements to pronounce a word. An alternative explanation may be that uncontrolled differences in item onsets between word sets influenced reaction times as measured by the voice key method, and consequently concealed an underlying frequency effect (Rastle & Davis, 2002).

Separately, the findings in each of these memory and language tasks constitute a replication of recent research. When interpreted together, they form a new and interesting set of findings. Using the same item and participant set in each paradigm, inhibitory neighbourhood effects in word recognition tasks emerged alongside beneficial neighbourhood effects in short-term memory and speech production. Facilitatory frequency effects were also observed in the majority of these measures.

It is plausible to suggest that phonological neighbourhood effects in Serial Recall are attributable to the important underlying role played by the speech output pathway. Furthermore, although frequency effects of similar magnitudes arose in input and output measures, the frequency effect in Serial Recall may primarily emerge through production processing. If recognition mechanisms were a major source of frequency effects in Serial Recall, adverse neighbourhood effects would also be predicted in this task. These results encourage a further specification of language-based memory models (e.g. Monsell, 1984, 1987; R. Martin et al., 1999), in that representational capacities associated with output phonology may have a greater role in Serial Recall, relative to input phonology.

The large-scale Lorch and Myers (1990) regression analyses again support this approach. Definition Naming (correct rates) was the only language measure to predict unique variance in Serial Recall. If a participant correctly named a word to its definition, they were more likely to remember that word in the short-term memory task. In contrast to Experiment Five, reaction times in Definition Naming did not predict recall. The remainder of the results were similar to those observed in the previous experiment. Lexical Decision, Word Identification in Noise, Delayed Repetition, and Speech Rate all failed to predict unique variance in Serial Recall performance in this analysis. As previously argued, it is not necessarily the case that the processing mechanisms underlying these tasks have no function in short-term memory. Rather, they may have a less central role in verbal memory relative to the processes critical to Definition Naming, which has predicted

Serial Recall in every experiment of which it has been a part. This would indicate the speech production pathway, and particularly the connections between semantics and output phonology, to be of primary significance in immediate verbal memory.

Finally, although spoken item length again predicted recall in the Lorch and Myers (1990) regression, it did not independently predict memory performance in this experiment. Item length varied with frequency and neighbourhood size, and a further regression analysis revealed that the latter two variables were the only independent predictors of variance in Serial Recall. It appears that slightly longer words were generally recalled better because they tended to be of higher frequency and from denser phonological neighbourhoods.

5.5 Chapter Summary

A second large-scale experiment was administered in Experiment Six, using identical memory and language measures to those featured in the previous chapter, and manipulating word frequency and neighbourhood size. Beneficial effects of both these variables were observed in Immediate Serial Recall, replicating recent findings (e.g. Hulme et al., 1997; Roodenrys et al., in press). Similar effects of both variables were also observed in Definition Naming and Speech Rate, with neighbourhood size also influencing Delayed Repetition. However, while frequency also facilitated performance in Auditory Lexical Decision and Word Identification in Noise, significant adverse neighbourhood size effects were observed in these input measures.

This experiment represents a replication of several strands of previous research within a single experiment using the same word set. The results emphasise the importance of stored language knowledge in verbal memory, and indicate that such factors emerge through the operation of speech production mechanisms. It appears that the temporary storage and retrieval of phonological information may be reliant primarily upon processes within the output pathway. This is further supported by regression analyses containing performance on every language task as predictors, which revealed that Definition Naming was again the only significant predictor of unique variance in Serial Recall.

Chapter Six

General Discussion

This thesis is concerned with the role played by language processing mechanisms in the temporary storage and retrieval of verbal information. A series of experiments examined immediate verbal memory performance alongside a variety of speech processing measures, using the same word set in each paradigm. Connections between these memory and language tasks were explored, both in terms of predictors of memory performance and the effects of language variables on each measure. The aim was to clarify the possible relationship between verbal memory and language mechanisms, and to identify how the representational capacities serving speech input and output processing may be involved.

7.1 Summary of the Experiments

Six experiments were reported in this thesis. Experiment One replicated the effects of concreteness and word length on immediate memory that have recently been reported (Walker & Hulme, 1999). An error analysis revealed these variables to influence the rates of order and item errors in Serial Recall. Specifically, more omissions were made on lists of long and abstract words, and more phonological approximations were made on short and abstract word lists. An advantage for short and concrete words was also observed in Definition Naming (on both correct rates and reports of tip-of-the-tongue experiences), Speech Rate, and Gating (an input task). These findings were interpreted as preliminary support for a language-based memory approach, in which information is coded in terms of meaning and processed by perception and production mechanisms. A regression analysis identified the latter as potentially more central to memory processing, as Serial Recall performance was predicted at an individual item and participant level by the two output tasks, but not by Gating.

These findings were partially replicated in Experiment Two, with children as participants. Significant concreteness effects were again observed in Immediate Serial Recall, although these were limited to later list positions. While concreteness did not influence order errors, a similar pattern of item errors to the previous experiment was found. The rate of phonological approximation errors was relatively high in this experiment, reflecting the still-developing language representations possibly underlying children's memory performance. Concreteness effects again emerged in Definition Naming and Gating, indicating speech processing to be the basis of such effects in children's recall (as claimed by Nation et al., 1999). However, concreteness did not influence Speech Rate, possibly due to the size of the item set.

An examination of individual differences revealed that Definition Naming was a better predictor of memory performance than Gating, while the strongest relationship overall was between recall and vocabulary knowledge. The within participant regression analysis showed Definition Naming to be the only significant predictor of Serial Recall performance.

Experiment Three again involved the manipulation of word concreteness, but this time with new measures of speech perception and production. The concreteness effect on Serial Recall was shown to be reliable, as this variable again influenced omission and phonological approximation error rates. A small but significant advantage for concrete words was also found in Speech Rate. In contrast, concreteness did not significantly affect Auditory Lexical Decision or Repetition. A series of regression analyses featuring each of these language tasks failed to find a significant predictor of Serial Recall performance.

Experiment Four focused more on input processing, with the effects of semantic ambiguity on STM and two recognition tasks being examined. A marginally non-significant disadvantage for ambiguous words was observed, although this variable did influence item error rates. Significant adverse ambiguity effects were found in Lexical Decision and Word Identification in Noise, replicating and extending the results reported by Rodd et al. (2000, 2002). It appears that, while semantic processing does influence perceptual mechanisms, this input-based semantic effect has only a marginal effect on memory. A post-hoc analysis of related sense effects was then performed. Advantages for words with more related senses were observed in Serial Recall and Word Identification in Noise, while the effect on Lexical Decision was marginally non-significant. The Lorch and Myers (1990) within participant regression analysis identified Speech Rate as the only unique predictor of recall. Neither of the input tasks predicted memory performance.

Chapter Four described a procedure in which the work of previous studies was drawn together in a single large-scale experiment. Concreteness was again the variable under examination, this time with multiple measures of language processing. The advantage for concrete words in Serial Recall was again observed, with significant effects on order errors, omissions, and phonological approximation errors. This variable also had large effects on

Definition Naming, with smaller but still significant effects emerging in Speech Rate (replicating previous findings). However, concreteness did not influence Lexical Decision, Word Identification in Noise, or Repetition performance. These findings suggest that the effects of concreteness on short-term memory primarily arise through speech output processing mechanisms. Furthermore, the regression analysis revealed Definition Naming (reaction time) to be the only language task to predict recall performance, further supporting the notion that speech production mechanisms may be more central than speech input mechanisms to immediate verbal memory.

Experiment Six, the final experiment, involved the same tasks as Experiment Five but in this case, word frequency and neighbourhood size were manipulated, rather than concreteness. In line with recent research (e.g. Hulme et al., 1997; Roodenrys et al., in press), high frequency words and words from large neighbourhoods were better recalled. Similar effects were also found in Definition Naming (correct rates and reaction times) and Speech Rate, while neighbourhood size also influenced Delayed Repetition. In contrast, while frequency did benefit recognition task performance, an advantage for words from small neighbourhoods was observed in both Lexical Decision and Word Identification in Noise (the opposite pattern to that found in recall). These findings replicate and extend previous research (e.g. Gordon & Dell, 2001; Griffin & Bock, 1998; Luce, 1986; Vitevitch, 2002) within a single study, and suggest output phonology to be more central than input processing in Serial Recall. This approach is bolstered by the regression analysis, which again identified Definition Naming as the only significant predictor of recall performance.

Overall, these experiments have suggested an important role for the language processing system in verbal short-term memory. It appears that verbal stimuli can be temporarily stored in terms of semantic and phonological information. Although many aspects of language processing would be involved in Serial Recall, the findings indicate mechanisms within the speech output pathway, specifically interactions between the conceptual system and output phonology, to be particularly influential.

7.2 Implications of the Immediate Serial Recall Data for Models of Verbal Short-Term Memory

It is important to re-evaluate existing models of immediate verbal memory in relation to the Serial Recall findings. The ability of the models described in Chapter One to account for findings such as concreteness, frequency, and neighbourhood size effects, as well as the regression analyses, will now be examined.

7.2.1 The Phonological Loop Model

According to Baddeley (1986), verbal information is temporarily retained in phonological form, within a speech-based, time-limited specialised memory store. The observation of significant and substantial word length effects in Experiment One provides further support for this approach, and replicates the robust word length effects that have previously been found (e.g. Baddeley et al., 1975). Similarly, that Speech Rate predicted memory performance in two experiments reflects some support for the notion that memory capacity is limited to the amount of information that can be rehearsed in a certain time. However, Speech Rate did not predict memory performance in the other four experiments.

In addition, it has already been established that the phonological loop model requires extension, to account for the influence of stored language knowledge on memory performance (e.g. Hulme et al., 1991, 1997; Walker & Hulme, 1999). This was again illustrated in each of the experiments reported here, as phonological and semantic effects emerged that would not be predicted by the original phonological loop model. Baddeley et al. (1998) proposed a revised conception of the phonological loop, wherein established language knowledge is used to supports short-term memory functioning. Although this might account for effects such as frequency, the approach is not well specified and is limited to phonological factors. It cannot explain the repeated observation of concreteness effects on item memory, or the smaller ambiguity and related sense effects found in Experiment Four. However, the Baddeley et al. (1998) argument that the phonological loop is critical to vocabulary learning fits well with the connections that emerged between children's vocabulary knowledge and Serial Recall performance in the individual differences analyses in Experiment Two.

7.2.2 The Burgess and Hitch Model

While this thesis is concerned more with temporary item representation, the model proposed by Burgess and Hitch (1992, 1999) retains a focus on memory for serial order. This model describes separate levels of nodes representing items, input phonemes, output phonemes, and a context-timing signal. Burgess and Hitch place the phonological short-term store at the layer of input phoneme nodes, with output phoneme nodes involved in output selection and response production. They claim serial order to be primarily stored through a 'moving window' context-timing signal, which codes the order of item representations at presentation. At retrieval and response production, the signal is reset and advances along the temporal sequence, activating the item representation connected to each state of the context window.

Although the primary focus of the Burgess and Hitch model is serial order, it is able to account for frequency effects, as the strength of connections between item nodes and the input and output phonemes would vary with frequency. This description of input and output phoneme layers has similarities with language-based models, although the emphasis on the input phoneme layer as a phonological store runs contrary to the argument put forward that phonological output mechanisms are critical to STM. The Burgess and Hitch approach does not address semantic coding, and so cannot account for the various concreteness, ambiguity, and sense effects uncovered. Similarly, the context to item associations that code serial position mean that the model would not predict significant neighbourhood effects, as words not presented in the list would not be sufficiently activated to influence performance (Roodenrys et al., in press).

7.2.3 The Gupta and MacWhinney Model

In the Gupta and MacWhinney (1997) model, items are represented as word nodes in a 'chunk' layer. These are directly connected to a phoneme layer, to semantic representations, and to a phonological store that encodes chunk sequences. The model emphasises a non-causal relationship between short-term memory and vocabulary acquisition, with a shared basis in the neural areas responsible for speech processing.

This model does allow for concreteness effects in short-term memory, through direct links between lexical semantic representations and temporary phonological coding. A detailed specification of the model would also provide an account of semantic-phonology interactions in Serial Recall, as illustrated by increased phonological approximation error rates on abstract words. The model is able to simulate frequency effects, through stronger connections for high frequency words between the word chunk nodes and other layers. Furthermore, the finding in Experiment Two that the most powerful predictor of STM development was vocabulary knowledge supports the Gupta and MacWhinney claim that these cognitive abilities rely on the same representational capacities.

However, while the model draws direct and useful connections between memory and speech processing, it implies that perceptual mechanisms are more important to phonological short-term memory. This is not supported by the present findings. In addition, the architecture described by Gupta and MacWhinney predicts inhibitory neighbourhood size effects in short-term memory, through an increased likelihood of activation of an incorrect chunk node by the phonological store at recall. The observation of better recall for words from large neighbourhoods found in Experiment Six contradicts this prediction.

7.2.4 The Feature Model

The feature model (Nairne, 1988, 1990; Neath & Nairne, 1995) describes primary memory, in which cues are maintained and constructed in the form of vectors of features. At recall, the remaining features contained in partially degraded primary memory traces are used as cues to establish, via a matching process, which of the items represented in a secondary memory search set were part of the presented list. If a cue has lost some of its features, the probability of inaccurately matching the primary and secondary traces will be increased.

This model is able to account for the concreteness effects observed in four experiments, through the matching process between primary and secondary memory. Word meaning would be represented by modality-independent features, with concrete words having more meaning-based features associated with them. Frequency effects could also be explained, with the features of high frequency words possibly being more active and accessible in secondary memory. However, the small but consistent rate of phonological approximation errors reported in each experiment cause a problem for the feature model, as representations in the secondary memory search set are effectively limited to experimental items. The model does not allow for the processing and retrieval of words other than those present in the experiment. This property of the model also means that it does not adequately explain neighbourhood effects.

7.2.5 Redintegration

The central element of redintegration theory was that verbal information is retained in an independent memory system, and that at retrieval, degraded traces are matched with and restored on the basis of long-term memory representations (e.g. Hulme et al., 1997, 1999; Schweickert, 1993). This process was assumed to be analogous to speech processing mechanisms. Furthermore, Walker and Hulme (1999) argued that the redintegration account could be extended to semantic as well as phonological processing.

The repeated observations of concreteness effects in Serial Recall compliment the findings of Walker and Hulme (1999), and support the notion that semantic coding is important in short-term memory. Thus, words may be temporarily coded in terms of meaning, with activation from these representations supporting phonological trace selection and restoration. Concreteness effects, sense effects, and the increased phonological approximation error rates observed on abstract words would support this. As Knott et al. (2000) claim, 'under a reconstruction type account, an important indicator of the absence of lexical support in Immediate Serial Recall should be phonemically related errors...' (p. 139).

Support for a process of phonological redintegration can be derived from the word frequency effects in Experiment Six, as in Hulme et al. (1997). The argument would be that the long-term representations of high-frequency words are highly active and more easily accessible, and so would enable efficient redintegration. An increased rate of approximation errors on short words relative to long words in Experiment One supports the argument that redintegration would be more effective and accurate on longer items, due to the greater cue remaining after degradation (e.g. Brown & Hulme, 1995;

Hulme et al., 1997; Schweickert et al., 1996). Redintegration theory also predicts the increased rate of approximation errors on lists of words from large neighbourhoods, observed in Experiment Six. The likelihood of selecting and restoring an incorrect item is increased when more similar-sounding words are also available.

However, this error rate contrasts with a much larger beneficial effect of neighbourhood size on memory performance, thus refuting the redintegration theory prediction. The implementation of a similar process in the OSCAR model of serial order means that this approach also fails to account for these findings. Similarly, the suggestion that redintegration is a process normally serving speech perception is at variance with the neighbourhood size findings, and also with the regression results in each of the experiments. It may be that a phonological redintegration process does operate in verbal short-term memory. However, the theory would require extension and specification, and reflects only one of many processes operating in immediate verbal memory performance.

Each of these memory models is able to account for aspects of the Serial Recall data reported in the preceding chapters. Word length and frequency effects are explained by several of the theories, while some models also allow for the influence of semantic processing. Nevertheless, when the findings are considered together, none of these memory models are able to provide a full account. In particular, there is an absence of a suitable account of beneficial neighbourhood size effects in short-term memory, with the majority of models predicting adverse or null effects. A successful model of immediate verbal memory should provide an explanation for each of the semantic and phonological effects observed.

7.3 Implications for a Language-Based Account of Verbal Short-Term Memory

As these variables are thought to reflect the influence of stored language knowledge, rather than acoustic or articulatory factors, it may be that language-based accounts of short-term memory (e.g. Gathercole & Martin, 1996; Monsell, 1984, 1987; R. Martin et al., 1999) can explain these findings. Indeed, the results obtained in the language processing measures do indicate connections between immediate verbal memory and the speech processing system. Temporary coding in memory tasks may reflect persisting activation of representations in a number of different storage capacities throughout the speech processing system, as suggested by Monsell (1984).

As outlined in Chapter One and illustrated in Figure 6.1, separable but interactive representational capacities are thought to exist within the speech system for the processing of word phonology and meaning. Furthermore, it is assumed by many models (e.g. Dell et al., 1997; Levelt et al., 1999; Monsell, 1987) that the perception and production of phonology is performed by distinct input and output lexicons. Under this approach, word meaning would be held in a central conceptual system and phonological information in input and output phonology. Although lexical in status, the view currently preferred is that these are distributed systems, with words represented through sets of nodes and the links between them (e.g. Allport, 1985; Funnell & Allport, 1987; Marslen-Wilson & Warren, 1994). An examination of the speech processing system in light of the reported findings will now be discussed, along with implications for a language-based account of verbal memory.

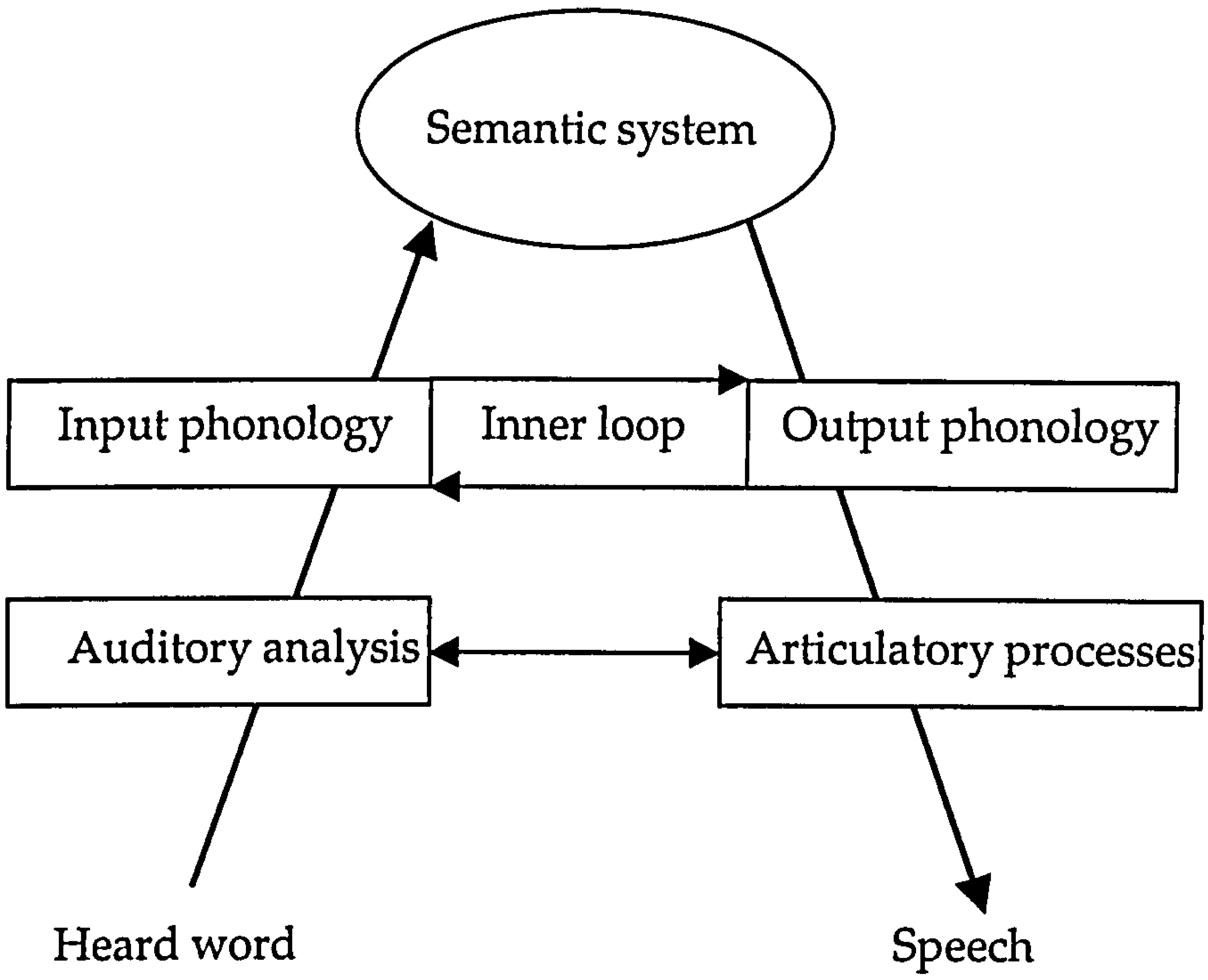


Figure 6.1. The main features of the speech processing system. Based on Monsell (1987).

7.3.1 The Speech Input Pathway

7.3.1.1 Phonological Processing in the Input Pathway

Monsell (1987) suggested that, when presented with auditory verbal input, a temporary and passive record is made, and compared with information in the phonological input lexicon (see Figure 6.1). The substantial word frequency effect observed in Lexical Decision and Word Identification in Noise would arise through this process, as the activation levels would be higher for a frequent word's constituent phonological segments and the links between these segments. This would enable efficient and accurate access to and processing of input phonology.

Several models have proposed that the speech perception system forms at least a partial basis for temporary phonological memory (e.g. Gathercole & Martin, 1996; Monsell, 1984, 1987; R. Martin et el., 1999). Such an approach would indicate the frequency effect to arise in short-term memory through input phonology functioning. Thus, high-frequency words would be easier to remember because their representations in input phonology would be more efficiently and accurately accessed at encoding, and/or would remain highly active throughout retention.

While the results of Experiment Six do not rule out an input processing contribution to the Serial Recall frequency effect, the pattern of results relating to neighbourhood size undermine any model places heavy emphasis on the role of speech perception. The disadvantage for words from dense neighbourhoods in recognition tasks would arise through increased competition between phonological representations disrupting processing (e.g. Luce & Pisoni, 1998; Marslen-Wilson & Zwitserlood, 1989; Norriset al., 2000). If the perception system and input phonology were critical to temporary information storage, the adverse effects of phonological competition would also impinge on immediate verbal memory. Instead, the beneficial effects of neighbourhood size that were observed in Serial Recall indicate the input pathway to be relatively less influential in such tasks. This refutes the claims made by Gathercole & Martin (1996), who argued that phonological memory is based within the perception system, and would therefore predict adverse neighbourhood effects.

7.3.1.2 Semantic Processing in the Input Pathway

The second form of linguistic information examined in this thesis was word meaning. It has already been suggested that this may be temporarily stored through persisting activation in long-term semantic representations. While it appears that the input pathway may not have a primary role in Immediate Serial Recall, it must still be a system integral to performing such a task, as auditory information needs to be initially processed and understood. The activation by input phonology of temporary semantic representations within the conceptual system, and the feedback of this activation to support processing in the input system may be a highly influential stage in immediate memory performance.

If this was the case, semantic variables would be predicted to influence input task processing, as this would involve the same interactions between input phonology and the conceptual system. In line with this, concreteness facilitated Gating in the first two experiments. The cohort model (Marslen-Wilson, 1987; Gaskell & Marslen-Wilson, 1997) proposes that multiple semantic representations are activated in response to a shared word onset. In Gating, the phonological representations of concrete words that are activated by the word onset stimuli would receive more of a boost in activation from semantics. This would make the phonological representations of the target word highly activated relative to its phonological neighbours, and contribute to earlier identification. Similarly, it may be that the temporary semantic representations of concrete words are more easily accessed by input phonology in Serial Recall, and provide more feedback support for temporary input-based phonological storage. This would place the locus of the concreteness effect as it arises in immediate verbal memory within the input pathway.

The absence of significant concreteness effects in Lexical Decision and Word Identification in Noise somewhat refutes this though. It appears that participants were able to perform both these input tasks without the aid of any increased semantic support from concrete words. One possibility is that Auditory Lexical Decision generally proceeds without being influenced by word concreteness, and that any previously reported effects such as imageability (e.g. Tyler et al., 2000) are the result of uncontrolled stimulus length differences. Alternatively, Plaut (1997) observed that participants will make lexical decisions on the basis of phonological information alone when this suffices (as in the third and fifth experiments), and will only fall back on semantic information when necessary. This may also be the case for Word Identification in Noise. Participants were able to identify the correct phonological form when embedded in noise, regardless of the levels of support conveyed from semantics. The finding that semantic processing was necessary to support performance in Serial Recall using the same word set would indicate such effects to emerge through processes other than speech perception.

While concreteness did not influence Lexical Decision or Word Identification in Noise performance, Experiment Four showed that these measures are not impervious to the effects of semantic processing. As predicted by the recent work of Rodd et al. (2000, 2002), adverse effects of semantic ambiguity emerged on both these measures. Activation of input phonology by auditory stimuli leads to competition between the semantic representations of ambiguous words (e.g. Gaskell & Marslen-Wilson, 1997; Hinton & Shallice, 1991). This slows and disrupts both semantic processing and the feedback to input phonology.

A model of memory based primarily on input processing would predict substantial ambiguity effects in Immediate Serial Recall. While significantly more omission errors were made on lists of ambiguous words, the effect on correct response rates was not significant. This would indicate a relatively less influential role for the input pathway in immediate verbal memory, and suggest that other semantic effects (e.g. concreteness) emerge in Serial Recall through the operation of other language mechanisms.

7.3.1.3 Implications of the Regression Analyses for Input Processing and Verbal Short-Term Memory

When considered together, the pattern of variable results indicate the input pathway to have a useful but perhaps secondary role in immediate verbal memory. The findings from the Lorch and Myers (1990) within participant regression analyses emphasise the second half of this statement. Using three different language tasks in six experiments, perception performance did not once predict Serial Recall. When attempting to remember a list of aurally presented items, it is clearly important that the list was correctly perceived and the items recognised and initially understood (as measured by the three input tasks). However, the regression analyses provide no evidence for a major role of the input pathway in retaining information up to the point of retrieval.

7.3.2 The Speech Output Pathway

The modular feed-forward (e.g. Levelt et al., 1999) and interactive feedback (Dell, 1986; Dell et al., 1997) accounts of speech production that were outlined in Chapter One are relevant to the output task findings. A common assumption of these models is that production begins with processing within the semantic system, proceeds through lemma and phonological processing, and culminates in the implementation of articulatory programs. The Levelt approach describes word production as a serial process, in which activation is conveyed through the output pathway in a modular and feed-forward fashion, with activation occurring at a given level only when node selection has taken place at the previous level. Thus, semantic processing in the conceptual system leads to activation and selection of a lemma representation. It is only following lemma selection that processing in output phonology can begin.

In contrast, the Dell (1986; Dell et al., 1997) account views the production pathway as a system in which activation flows relatively freely, forwards and backwards between representational levels, with simultaneous activation possible at all levels of the system. Ongoing semantic activation is able to influence processing in output phonology, and vice versa (although the Dell et al., 1997, model emphasised the possible restrained nature of this interaction). The language task findings may clarify which of these models provides the more accurate account of output processing. This in turn would have implications for a model of memory that includes a role for speech production.

7.3.2.1 Semantic Processing in the Output Pathway

Under a production model such as Dell et al. (1997), the significant concreteness effects that were observed in Definition Naming in three experiments would reflect increased activation conveyed to output phonology representations of concrete words from the conceptual system. Such a process would affect the speed and accuracy of word retrieval, and make partial failures (tip of the tongue situations) less likely. These findings reflect the influence of semantic processing on the speech production system, and indicate a shared basis with similar effects in Serial Recall. Concrete words may therefore be better remembered because the temporary activation of representations in the semantic system is more resistant to degradation, and because these representations will provide more support for temporary coding in output phonology during encoding, retention, and retrieval.

The semantic system has also been shown to influence performance in output tasks that do not necessarily require such support, although these effects are much smaller and less reliable than in Definition Naming. For example, the repeated articulation of a word in Speech Rate requires rapid access to and refreshment of output phonology representations, to enable efficient implementation of the correct articulatory programs. The boost provided by the semantic representations of concrete words appears to facilitate this process. These findings would favour a production model in which activation cascades between representational levels (e.g. Dell, 1986), although the modest size of these effects relative to Definition Naming suggest a restrained model (e.g. Dell et al., 1997) to be more appropriate. As noted by Dell et al. (1997, p.829), 'the semantic level has only mild effects at the phonological level'. This would be the case in measures that are phonological and articulatory in nature such as Speech Rate, with semantics serving to provide supporting activation. A similar explanation may be applicable to Serial Recall, with semantic activation providing support for phonological memory processing.

Far from undermining this argument, the absence of significant concreteness effects in Delayed Repetition is in line with such an approach. As previously observed, semantic variables only influence visual naming (a similar task) when phonological processing is less efficient, for example, when processing low-frequency words (Lipchacz et al., 1999; Strain et al., 1995). De Groot (1989) observed small and non-significant concreteness effects in visual naming, similar in magnitude to those found in Experiment Three and Experiment Five. Thus, when processing at the phonological level is efficient (as it generally is in Delayed Repetition with moderate- or high-frequency words), the mild effects of semantic activation do not have a significant effect.

7.3.2.2 Phonological Processing in the Output Pathway

It has been suggested that word meaning is temporarily coded through persisting activation in the conceptual system, and that the connections with the speech production pathway may be more critical to short-term memory than the links to perception. Integrating this with a language-based model of memory would indicate the output phonology lexicon to have a key role in temporary phonological storage. This is supported by the equivalent word frequency and neighbourhood size effects on the same items in Serial Recall, Definition Naming, Speech Rate, and (for neighbourhood size) Delayed Repetition.

Neighbourhood effects in production tasks provide support for interactive activation models (e.g. Dell et al., 1997). The facilitatory effects are thought to arise through interactive feedback between output phonology, lemma nodes, and semantic representations (Gordon & Dell, 2001; Vitevitch, 2002). Phonemic segments of the target word feed activation back to the target word lemma and semantic representations, and also the lemmas and semantic representations of neighbouring items. Renewed activation is then fed forward to the phonological nodes of the target word and neighbouring words, increasing the activation of each of these representations. The phonemes of words from large neighbourhoods therefore receive activation from multiple semantic and lemma representations. This interactive process would benefit Definition Naming, Repetition, and Speech Rate. It can also account for the overall facilitatory neighbourhood effects and the increased rate of phonological approximation errors observed on recall of words from large neighbourhoods in immediate verbal memory.

This language-based approach would also identify the output pathway as the primary locus of word frequency effects in Serial Recall. Thus, the representations of high frequency items in output phonology would be more easily accessed, would subsequently remain highly activated, and would propagate further activation throughout the speech processing system. If it were assumed that the same representational capacities served production and short-term memory, this account would provide an effective and parsimonious explanation of frequency effects in these measures.

One potential problem with this claim was that frequency did not influence Delayed Repetition performance. One possibility is that this is a correct null effect, and that Delayed Repetition does not crucially depend upon access to phonological representations. Forster and Chambers (1973) noted that frequency effects do not consistently arise in tasks measuring the execution of articulatory movements to pronounce a word. This would not seriously undermine an output-centric memory model, as each of the language tasks were selected to be sensitive to different factors, and frequency effects were still observed on two other production measures. A second possibility is that problems with the voice key method of reaction time measurement (as noted by Rastle & Davis, 2002) concealed any frequency effects in this task.

7.3.2.3 Implications of the Regression Analyses for Output Processing and Verbal Short-Term Memory

While no links were found between input and Serial Recall in the Lorch and Myers (1990) regression analyses, memory performance was predicted by speech production in five out of the six experiments. Specifically, Definition Naming was consistently connected to Serial Recall, so that the faster or more likely a participant was to correctly name a word to its definition, the better their recall for that word. Speech Rate also predicted memory performance in two experiments, with faster repeated articulation linked to improved memory. This would indicate speech output mechanisms to be important in immediate verbal memory, with the processes critical to Definition Naming being particularly influential.

Therefore, in every experiment of which it was a part, Definition Naming produced the same variable effects as Serial Recall and predicted within participant variations in memory performance. The operational and representational capacities crucial to Definition Naming can be identified as the conceptual system, output phonology, and the bi-directional links between these levels. Successful performance requires high levels of activation being efficiently conveyed between semantic and phonological processing, resulting in the accurate activation and selection of target word nodes in output phonology. On the basis of the results reported in this thesis, it would be plausible to identify these processes as being central to temporary verbal information storage and retrieval.

Further support would be derived for a production-based model had Delayed Repetition predicted recall performance, as both tasks involve the retention of phonological activation. However, while Serial Recall performance is determined by the degree of information loss, this factor is rarely of importance in normal adult Delayed Repetition performance. In addition, variables such as item onset are critical to repetition reaction time (e.g. Rastle & Davis, 2002), but not to probability of successful recall. Such differences would explain why speed of repetition for each word did not predict verbal memory performance.

7.4 An Overview of the Language and Memory System

A tentative language-based approach to verbal short-term memory, particularly implicating speech output mechanisms, has already been roughly outlined while discussing the memory and language task findings. It is useful to bring these claims together to summarise such a model and address the relevant issues.

The model outlined contains elements from a range of previous theoretical work. It constitutes a further specification of the Monsell (1984, 1987) model of language processing and short-term memory, and uses the Dell et al. (1997) interactive model of speech production to describe certain mechanisms within the output pathway. Furthermore, it is useful to refer to the Burgess and Hitch (1999) and OSCAR (Brown et al., 2000) serial order models, and Gupta and MacWhinney (1997). A schematic overview of the system, based on the Monsell (1984, 1987) speech processing system (Figure 6.1) is illustrated in Figure 6.2.

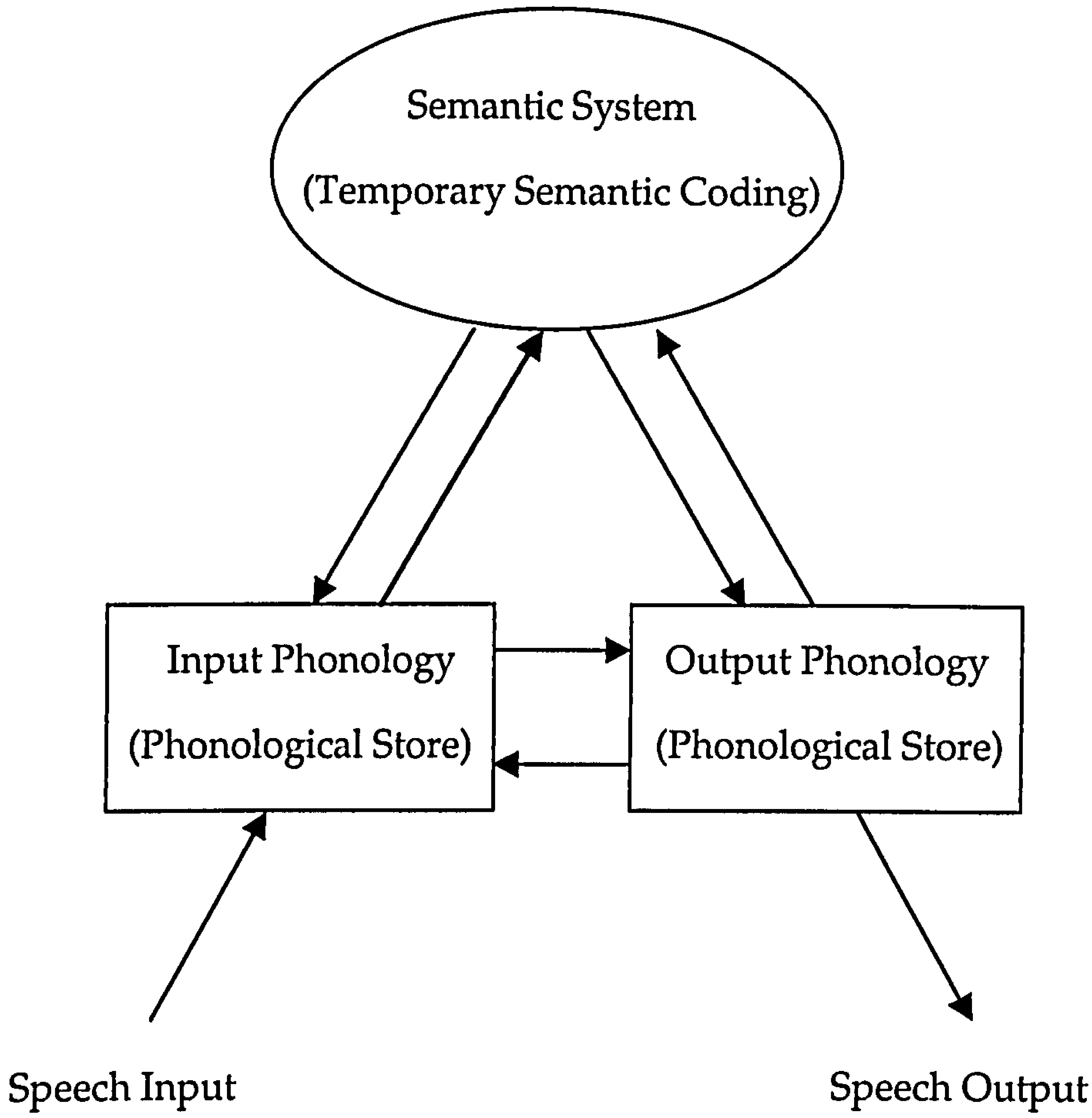


Figure 6.2. Schematic diagram of the language and verbal memory system

An approach similar to the one proposed by Monsell (1984) is adopted, in that the temporary storage of verbal information utilises multiple representational capacities throughout the speech processing system. Following auditory presentation, the appropriate representation in input phonology is activated, and remains so throughout storage. Meanwhile, the perception process continues so that word meaning is accessed. This activation of the semantic representation subsequently persists (degradation willing) up to the point of retrieval, thus forming the basis of semantic short-term memory.

It is argued that, on the basis of the experimental findings reported in this thesis, the primary form of temporary phonological representations in Serial Recall are output codes. Thus, representations in output phonology are activated by both input phonology and the conceptual system, and subsequently form the central basis of phonological short-term memory. It is primarily at this level of representations that frequency and neighbourhood effects would emerge in immediate verbal memory.

A 'summation' effect analogous to the one described by Hillis and Caramazza (1991) for repetition may operate in verbal short-term memory, in that various processing capacities may combine to produce successful storage and retrieval. Therefore, when certain elements of the system are impaired or employed in other functions, STM performance levels fall. However, performance is held above zero by the operation of the remainder of the system. In this way, information can be temporarily retained even when the primary focus of verbal storage, the output pathway, is impaired (e.g. aphasic patients) or constrained (e.g. by articulatory suppression). This would imply a useful but perhaps secondary role for the input pathway in Serial Recall performance.

The model compliments the claims made by Gupta and MacWhinney (1997) regarding the relationship between vocabulary development, verbal short-term memory, and speech processing. As illustrated by the individual differences analyses in Experiment Two, close connections have repeatedly been observed between these cognitive abilities in children. In line with the Gupta and MacWhinney model, this would be because vocabulary and memory rely on the same representations within the speech processing system. If a child has a word in his or her vocabulary (including knowledge of sound and meaning), temporary retention and retrieval of that word will proceed based on these representations. If not, STM performance will rely on new, weak connections between sub-lexical phonological representations, with an absence of support from semantic processing.

7.4.1 Temporary Storage and Retrieval within the Output Pathway

This model therefore adopts the multiple storage capacity view proposed by language-based models of memory (e.g. Howard & Franklin, 1988, 1990; Monsell, 1984, 1987). While the present findings indicate output processing to be more important in Serial Recall, verbal information is also temporarily held in the input pathway. However, the role of this stored information may be limited to initial encoding, support for output processing, and as a 'back-up' system when production mechanisms are busy or impaired. In contrast, it may be that representations in output phonology are activated by input phonology and the conceptual system at list presentation, and form the primary basis of phonological short-term memory. It is therefore important to closely examine verbal memory functioning within the speech output pathway, as measured by Immediate Serial Recall.

7.4.1.1 Semantic Memory within the Output Pathway

As in Monsell (1984, 1987), word meaning is coded in short-term memory tasks through persisting activation of representations within the central conceptual system. These are activated by input phonology at encoding and remain active to the point of retrieval. Although temporal and interference-based degradation of this activation will occur, the notion of semantic redintegration suggested by Walker and Hulme (1999) is not accepted. This process would predict the occurrence of semantic approximation errors in Serial Recall. Such errors were extremely rare in the six experiments reported in this thesis.

Instead, semantic representations convey activation to and receive it from other processing capacities throughout retention. This reflects the nature of a system in which interactive activation feeds forward and back between levels (as in Dell, 1986; Dell et al., 1997), serving to keep representations active at different levels of the system. In line with the experimental findings concerning Definition Naming, it is the connections between the semantic system and output phonology that are of most importance in Serial Recall. These levels interact and ensure node activation persists up to the point of word retrieval and response production. At this point, the remaining semantic activation regarding the relevant list item sends a boost to output phonology, aiding activation and selection of appropriate target phonology. Concrete words will be easily accessed, more resistant to degradation, and will provide more activation for nodes in output phonology throughout retention and at retrieval.

7.4.1.2 Phonological Memory within the Output Pathway

Phonological short-term memory is heavily reliant upon output phonology in this model. These representations are activated at encoding and remain the focus of phonological storage to the point of retrieval. The phonological lexicon is assumed to be a distributed system comprised of sub-lexical phonological nodes, with words represented as links between these phonemic segments. Novel information such as nonwords would then be stored via the creation of new connections between sub-lexical segments. The fragility of these new connections, and the absence of supporting semantic representations, would result in the lexicality effect in immediate verbal memory (Hulme et al., 1991).

The frequency effect in Serial Recall would primarily arise through the sub-lexical phonological representations of frequent words being easily accessed, along with highly active connections between these constituent segments. These representations would be more resistant to partial or complete information degradation, and would enable more efficient and accurate response production. While this would be true for storage in input and output phonology, it is the latter that makes the major contribution to frequency effects and overall performance.

Neighbourhood size would influence performance through interactive activation between semantic and output phonology representations increasing and strengthening the activation of target word nodes at each of these levels, particularly phonology. The temporary semantic and output phonology representations underlying much of Serial Recall would be highly activated for words from dense neighbourhoods throughout storage and retrieval as a result of increased bi-directional excitatory interaction between representational levels. This would ensure efficient retention, and support word retrieval processes at response production.

The distributed nature of the output phonology lexicon would give rise to phonological approximation errors in Serial Recall. As discussed, phonological information would be stored in the form of activated sub-lexical nodes and the links between them. As a result of this architecture, words sharing phonemic segments with the target words will also be activated. The degradation of node activation, and noise within the system, would increase the probability that nodes representing a phonologically similar word would be more highly activated than the target word at retrieval, thus leading to approximation errors. This would be more likely for low-frequency words, words from large neighbourhoods, and abstract words (due to the lower levels of support from semantic processing).

7.4.1.3 The Source of Lexical Effects in Serial Recall

Under this approach, lexical effects such as frequency, concreteness, and neighbourhood size, would have two basic sources in the production pathway. Firstly, such effects would emerge during item retention. The representations of high-frequency words, words from large neighbourhoods, and concrete words would be highly activated and relatively resistant to degradation. This would impinge on node activation, on activation of the links between nodes, and on interactions between representational levels.

A second source of lexical effects would be during the actual process of item retrieval and response production. The persisting activation within the conceptual system and output phonology representing each list item would be accessed, and the speech production process would then proceed. Due to the effects of variables on output mechanisms (as measured by the speech production tasks in this thesis), this process will be more efficient and accurate for certain items (e.g. frequent and concrete words).

7.4.1.4 The Semantics-Output Phonology Link

This approach emphasises the importance of interactions between the conceptual system and output phonology, for the temporary retention of a target word's meaning and sound. It is necessary to note, however, that production models (e.g. Butterworth, 1989; Dell, 1986; Dell et al., 1997; Fay & Cutler, 1977; Levelt, 1989; Levelt et al., 1999) often assume an intermediate level between semantic and phonological representations. This level of nodes, often termed the lemma level, is thought to contain syntactic information and bridge what may otherwise be an arbitrary relationship between meaning and sound. If Serial Recall theory can indeed be integrated with speech production models, a further examination of the influence of such an intermediate level in verbal memory would be required. However, as the primary experimental and theoretical focus of this thesis is concerned with how semantic and phonological information is temporarily stored, confident assumptions concerning the role of a possible lemma level cannot be made. Therefore, the present version of the model as outlined in Figure 6.2 is limited to an illustration of how semantic and phonological information may be retained within the language system.

7.4.2 Memory for the Serial Order of Verbal Information

The language-based model that has been outlined is primarily concerned with item representation. A detailed specification of how items may be coded in terms of their serial order is outside the remit of the present work. Nevertheless, it is useful to briefly suggest how a potential set of mechanisms for order memory may operate alongside speech-based item representations. R. Martin et al. (1999) posited the need for temporary phonological and semantic representations, separable from stored language knowledge, to explain order issues such as how item repetitions are represented (e.g. a list such as 'chair leaf chair book'). A unitary memory model in which information concerning multiple items is temporarily retained in the form of persisting activation in long-term memory needs to account for questions concerning serial order.

A possible solution for this problem can be derived from models of serial order such as OSCAR (Brown et al., 2000), and Burgess and Hitch (1999). One potential mechanism identified by Burgess and Hitch was competitive queuing (CQ; Houghton & Hartley, 1996), a process whereby item representations are selected on the basis of the highest activation level, and are then immediately suppressed, thus enabling selection of the next item. This process could operate on nodes within both semantic and phonological levels, aiding selection of the appropriate representations for response production. The suppression element of the CQ process would explain the Ranschburg effect (Jahnke, 1969), that is, the tendency to overlook the second item in a list containing repeats (e.g. the second 'chair'). It would also account for the rarity of item repetitions in response to non-repeated lists (Burgess & Hitch, 1999).

A second mechanism featured in Burgess and Hitch (1999), and OSCAR, was a context-timing signal, connected to item representations. A similar mechanism could be added to the model presently being discussed.

Each list item would be coded in terms of the current state of a 'sliding window' context-timing signal. This level of coding may come in the shape of output from sets of internal oscillators and would be linked to item representations. In this way, the activated nodes in semantic and phonological memory pertaining to different test items will be connected to varying states of the timing signal, thus coding serial position. At recall, the context-timing signal is repeated from the start of the list. The representations of the word in input phonology, output phonology, and the semantic system connected to each successive state would then be re-activated, and the actual process of speech production would then proceed. This would provide a possible mechanism for 'kick-starting' the production process for each test item at retrieval.

The storage of information as persisting activation within output phonology and the addition of a context-timing signal would provide an explanation of increased order error rates on phonologically similar word lists (e.g. Henson, Norris, Page, & Baddeley, 1996; Wickelgren, 1965). Similar lists would be represented by the activation of a small set of nodes in output phonology. As the context signal advances at retrieval, these nodes will be repeatedly activated at different states of the signal, increasing the likelihood that a word will be selected for output at an incorrect serial position.

This is a tentative approach to serial order coding within a language-based memory system and as such requires further work, or at least a large degree of 'fleshing out'. Nevertheless, the integration of a model for item memory with serial order mechanisms may allow a plausible description of how persisting activation of multiple representations may be coded in what is essentially a unitary memory system.

7.4.3 Criticisms and Future Research

It important to consider the potential drawbacks contained within the experimental and theoretical work presently discussed. One issue worth considering is the possibility that the locus of storage in the speech system may vary as a function of the memory task used. Each of the experiments that were reported in this thesis featured Immediate Serial Recall as the measure of memory performance. This means that the conclusions are, for the time being, somewhat task-specific. While this paradigm requires accurate perception and production, and places great importance on storage functioning, it does involve a particularly crucial role for word retrieval and output processing. Therefore, the nature of this task may result in a greater reliance on information stored within the output pathway.

In contrast, a memory measure tapping item storage without any demands on actual item production, such as serial recognition, matching span, or probed recall, may require a more influential role for input processing (e.g. Allport, 1984; R. Martin et al., 1999). While further research is required, it is certainly plausible that the focus of storage would vary to an extent with task demands. For example, the storage of verbal information in the perception pathway, and access to this information at the response stage, may be relatively more critical in serial recognition than in serial recall. Similarly, it may be that the output pathway is even more important in visually presented serial recall than in the verbally presented task featured in this thesis, due to the absence of auditory input and the need for phonological re-coding of orthographic information by production mechanisms (e.g. Baddeley, 1986). However, the view currently adopted is that these between-task variations in the focus of retention are relatively small, and that production processing has an important role in all immediate verbal memory performance.

A related possibility is that, rather than item retention varying with memory tasks, the influence on the memory and language system by different procedures and response methods give rise to between-task variations. For example, Gathercole et al. (2001) noted a reduced lexicality effect in serial recognition, and Walker and Hulme (1999) failed to observe a concreteness effect in matching span. This would suggest lexical effects to arise only at word retrieval, and not influence item retention. Alternatively, these effects may be concealed in matching span, as the re-presentation of item information makes order retention relatively more important. Again, further research is required to investigate such possibilities. The manipulation of factors such as input and output demands, item and order storage importance, and response methods in memory tasks would therefore enable a broader picture of memory processing to be developed, particularly in combination with measures of language processing. Nevertheless the findings observed using Immediate Serial Recall have provided a useful and interesting insight into memory and language processing.

Another potential problem is the possibility that the manipulation of language variables may have influenced the results of the Lorch and Myers (1990) regression analyses. That is, memory performance was predicted by production tasks only because certain word variables had significant effects on each of the measures. Two points of response can be made to this. Firstly, words are remembered better and/or processed better in language tasks as a result of their particular features. If a certain feature of a word (e.g. its frequency) has equivalent effects on the ease of recall and of production, and subsequently contributes to a prediction of performance on that word in one task by performance in the other, this still represents support for important connections between those tasks. Secondly, it is clear from the findings that significant regression results did not simply 'blindly' arise whenever a variable had effects on memory and language task performance. Examples can be drawn from every one of the six experiments to support this. This would therefore indicate the significant findings that were observed in the

Lorch and Myers (1990) regression to reflect genuine links between memory and language processing.

While the model represents a more detailed extension of earlier language-based theories, it does remain somewhat under-specified concerning a number of details. For example, the direction of the experimental findings has meant that processing within and contributions made by the input pathway have been somewhat neglected, relative to production mechanisms. In addition, the focus of the experimental and theoretical work on item storage means that a more detailed consideration of serial order coding is necessary. Future experimental and theoretical work is also required concerning a possible role for syntactic and morphological information, and a lemma level of processing in STM. This would enable a further integration of memory and speech production models.

7.4.4 Implications of this Work

The model of immediate verbal memory that has been outlined constitutes a reassertion and detailed specification of the multiple capacity language-based approach as described by Monsell (1984, 1987). The basic tenet of such a model is that verbal information is temporarily held through persisting activation in a variety of different representational capacities developed for the processing of speech. In particular, while all elements of the language system from initial auditory processing through to articulatory planning would be influential in temporary information storage, the experimental findings reported in this thesis indicate that it is mechanisms within the speech output pathway that are of central importance.

An attempt has been made to describe how information may be temporarily stored within the various long-term language stores, and how such activation may interact within and between levels. Furthermore, the theoretical advances that have recently been made have enabled a degree of integration between a language-based memory approach and other models of memory processing, such as Burgess and Hitch (1999), Gupta and MacWhinney (1997), and OSCAR (Brown et al., 2000). This use of a combination of theoretical work provides an effective account of a variety of short-term memory phenomena, such as language variable effects, error patterns, and developmental findings.

The language-based memory model currently described sets out a plausible explanation of verbal short-term memory and speech processing within a single (multi-component) cognitive system. An important and explicit element of this approach is that all aspects of verbal memory, from how we temporarily retain information to how we store it long-term, are performed within a unitary system. Verbal short-term memory traces are based on the temporary activation of stored language knowledge. This approach would have implications for memory and wider cognitive research, from developmental psychology and language learning through to neuropsychology.

7.4 Conclusions

The experiments reported in this thesis examined how verbal short-term memory, as measured by Immediate Serial Recall, related to wider cognitive language functioning. Beneficial effects of word concreteness on memory performance were consistently observed, suggesting an important role for semantic information in temporary verbal memory. The accompanying pattern of effects this variable had on performance in a variety of language tasks indicated that concreteness effects arise in Serial Recall primarily through processing within the central conceptual system, and through interactions with the speech output pathway. Semantic ambiguity, a variable thought to impinge on interactions between input phonology and the semantic system, had only a marginal influence on memory performance. The influence of lexical phonology was also examined, with large frequency and neighbourhood size effects emerging in Serial Recall in the final experiment. The corresponding results obtained in the language processing measures indicated both these effects to effects to arise in memory through the operation of the speech production system, particularly output phonology. Finally, regression analyses revealed that each participant's recall of each item was related to how well they could produce that word (repeatedly and rapidly, or in response to it's definition), but not their ease of perception and recognition. While a number of existing memory models give useful and adequate explanations for a number of these findings, an extension of the multiple capacity language processing model described by Monsell (1984, 1987) was identified as providing the best fit with the data. This approach rejects the notion of separable semantic and phonological STM, and instead views immediate verbal memory as persisting activation of representational capacities within the long-term language system. Specifically, the findings indicate speech output mechanisms to be more critical than input processing to Immediate Serial Recall.

Appendices

	Concrete Rating	K-F Frequency	Syllables	No. of Phonemes	Item Length (ms)
Tooth	7	20	1	3	600
Plate	6.5	22	1	4	530
Cream	6.25	20	1	4	540
Fruit	6.19	35	1	4	590
Star	6.19	25	1	3	730
Flash	4.56	30	1	4	820
Lock	5.88	23	1	4	580
Plug	5.81	23	1	4	500
Path	5.75	44	1	3	630
Wave	5.38	46	1	3	680
Net	5.25	34	1	3	565
Golf	5.13	34	1	4	620
Lift	5	23	1	4	600
Joint	5.81	39	1	4	560
Cheek	6.06	20	1	4	550
Jet	6.94	29	1	3	490
Mean	5.76	29.19	1	3.625	599.06
Submarine	6.94	27	3	8	840
Magazine	6.75	39	3	7	700
Musician	6.25	23	3	8	640
Monument	6.25	21	3	9	740
Factory	6.19	32	3	7	650
Gallery	5.94	31	3	6	530
Customer	4.86	27	3	7	660
Furniture	5.86	39	3	7	760
Funeral	5.65	33	3	8	740
Reporter	5.50	20	3	6	710
Avenue	5.38	46	3	6	600
Horizon	5.31	27	3	6	750
Composer	5.19	31	3	7	750
Gentleman	5.13	21	3	8	660
Engineer	5.13	42	3	6	720
Studio	5.13	31	3	7	910
Mean	5.72	30.63	3	7.06	710

Table A1. Concrete one-syllable items used in Experiment One and Experiment Two, and concrete three-syllable items used in Experiment One

	Concrete Rating	K-F Frequency	Syllables	No. of Phonemes	Item Length (ms)
Guilt	1.86	33	1	4	480
Trend	1.86	46	1	5	630
Luck	1.94	47	1	3	490
Pride	2.13	42	1	4	560
Shame	2.13	21	1	3	600
Fail	2.19	37	1	3	680
Wise	2.25	36	1	3	620
Phrase	2.31	34	1	4	470
Mood	2.34	37	1	3	610
Aim	2.34	37	1	2	520
Myth	2.44	35	1	3	590
Glad	2.44	38	1	4	530
Pause	2.76	21	1	3	660
Brave	2.56	24	1	4	610
Trace	2.81	23	1	4	600
Bid	2.56	22	1	3	460
Mean	2.31	33.31	1	3.44	586.25
Dignity	1.81	35	3	7	620
Dilemma	1.94	25	3	6	550
Loyalty	2	22	3	6	750
Origin	2.06	44	3	6	650
Distinction	2.06	41	3	10	780
Compromise	2.06	20	3	9	860
Mystery	2.13	39	3	7	680
Permission	2.13	27	3	7	620
Consciousness	2.13	30	3		870
Coverage	2.31	25	3	7	700
Perspective	2.38	26	3	9	780
Substitute	2.88	22	3	10	940
Offering	2.63	28	3		620
Illusion	2.44	37	3	6	710
Amateur	2.56	25	3	5	550
Discipline	2.63	27	3	8	590
Mean	2.26	29.56	3	7.36	704.38

Table A2. Abstract one-syllable items used in Experiment One and Experiment Two, and abstract three-syllable items used in Experiment One

Word	Definition
Tooth	One of the hard bone-like bodies set in the jaws, used for biting and chewing.
Plate	A shallow, usually circular dish on which food is served.
Cream	The fatty part of the milk, which rises to the top.
Fruit	Any fleshy part of a plant that supports the seeds and is edible.
Star	One of the many celestial objects visible in the night sky as a point of light.
Flash	A sudden short blaze of intense light or flame.
Lock	A device fitted to a gate, door, etc, to keep it firmly closed.
Plug	A device with one or more pins which connects an appliance to an electricity supply.
Path	A road or way, often a narrow trodden track.
Wave	One of a sequence of ridges or undulations that moves across the surface of the sea.
Net	An openwork fabric of string or wire mesh.
Golf	A game in which a ball is struck with clubs into a series of holes on a grassy course.
Lift	A compartment which moves between floors in a building in a vertical shaft.
Joint	The junction or connection between two or more parts or objects.
Cheek	Either side of the face, especially the part below the eye.
Jet	A thin stream of liquid or gas which is forced out of a small hole.
Submarine	A vessel, usually a warship, capable of operating under the sea.
Magazine	A periodical paperback publication containing articles, fiction, photographs, etc.
Musician	A person who plays music, especially as a profession.
Monument	An obelisk, statue, building, etc, erected in commemoration of a person or event.
Factory	A building where goods are manufactured in large quantities.
Gallery	A room or building for exhibiting works of art.
Customer	A person who buys goods or services.
Furniture	The moveable objects that equip a room or house.
Funeral	A ceremony at which a dead person is buried or cremated.
Reporter	A person who gathers news for a newspaper or broadcasting organisation.
Avenue	A broad street, often lined with trees.
Horizon	The apparent line that divides the earth and the sky.
Composer	A person who writes music.
Gentleman	A cultured, courteous, and well-bred man.
Engineer	A person in the profession of applying scientific principles to design, construction, and maintenance.
Studio	A room in which a musician, photographer, or artist works.

Table B1. Definitions for concrete items from Experiment One

Word	Definition
Guilt	The fact, state, or feeling of having done wrong or committed an offence.
Trend	A general tendency or direction.
Luck	Events that are beyond control and seem subject to chance.
Pride	A feeling of honour and self-respect.
Shame	A painful and embarrassing emotion resulting from having done something wrong.
Fail	To be unsuccessful in an attempt.
Wise	To have an understanding of that which is good or true, together with sound judgement.
Phrase	A group of words forming a unit of meaning in a sentence.
Mood	A temporary state of mind or temper.
Aim	To point or direct at a particular person or object.
Myth	A story about superhuman beings of an earlier age.
Glad	Happy and pleased.
Pause	To cease an action temporarily.
Brave	Having or displaying courage, resolution, or daring.
Trace	To copy by drawing over the lines visible through a superimposed sheet of transparent paper.
Bid	To offer an amount in an attempt to buy something.
Dignity	A serious, calm, and controlled behaviour of manner.
Dilemma	A situation requiring a choice between two equally undesirable alternatives.
Loyalty	A feeling of duty and allegiance.
Origin	The point, source, or event from which something develops.
Distinction	The act or an instance of classifying or differentiating between things.
Compromise	Settlement of a dispute by concession on all sides.
Mystery	An unexplained or inexplicable event, phenomenon, etc.
Permission	Authorisation to do something.
Consciousness	That which makes us aware or our surroundings, motivations, and thoughts.
Coverage	The reporting or analysis given to a particular subject or event.
Perspective	A way of regarding situations or facts and judging their relative importance.
Substitute	To take the place or put in place of another person or thing.
Offering	Presenting something for acceptance or rejection.
Illusion	A false appearance or deceptive impression of reality.
Amateur	A person who engages in an activity, especially a sport, as a pastime rather than for gain.
Discipline	Strict rules of behaviour imposed for the improvement of physical abilities, self-control, etc.

Table B2. Definitions for abstract items from Experiment One

Word	Definition
Tooth	One of the many hard white things in your mouth, which you use for biting and chewing.
Plate	A circle-shaped dish that you eat food off.
Cream	The fatty liquid which you get from milk, which you can put on strawberries.
Fruit	The normally sweet-tasting parts of a plant which you can eat.
Star	One of the many dots of light shining in the sky at night-time from space.
Flash	A sudden short burst of bright light.
Lock	A thing fitted to a door which stops people from opening it, unless they have a key.
Plug	A thing with 3 pins which you connect to a socket, to get electricity.
Path	A narrow road or track which you walk down.
Wave	There are lots of these up and down movements on the surface of the sea, especially when it is stormy.
Net	A thing made out of string or wire with holes in, which you can use to catch fish with.
Golf	A game in which you use clubs to try and hit a ball into a hole on a grassy course.
Lift	You can go up or down between the floors of a building in one of these.
Joint	The part where two objects join or connect to each other.
Cheek	The part of your face which is just below your eye.
Jet	A thin stream of liquid or gas which squirts out of a small hole.
Guilt	The feeling you get when you do something wrong or break the law.
Trend	A style which people follow for a while to be fashionable.
Luck	You have this when you have good fortune and when things go your way.
Pride	A good feeling you have about yourself when you have done something well.
Shame	A bad and embarrassing feeling you get when you have done something you shouldn't have.
Fail	To be unsuccessful when trying to do something.
Wise	To have wisdom about a lot of things is to be this.
Phrase	A group of words which mean something, in a sentence.
Mood	A feeling or temper you have which lasts for a short while.
Aim	What you do when pointing or shooting something to try and hit a target.
Myth	A story or fairytale about magical things that happened long ago.
Glad	Happy and pleased.
Pause	To stop doing something for a bit, before starting to do it again.
Brave	You would be this if you had courage and dared to do dangerous things.
Trace	To copy a picture by drawing over the lines you can see on a see-through piece of paper.
Bid	To offer some money to try to buy something.

Table C1. Definitions of concrete and abstract items for Experiment Two

	Concrete Rating	Frequency Rating	K-F Frequency	AOA Rating	No. of Phonemes	Item Length (ms)
Bar	6.07	5.73	82	4.6	2	635
Barn	6.8	3.27	29	4.07	3	770
Bomb	6.53	3.27	36	4.6	3	675
Breath	4.8	4.87	53	4.27	4	700
Cream	6.27	5.27	20	3.4	4	830
Desk	6.8	4.8	65	3.67	4	760
Drug	5.47	4.07	24	5.6	4	645
Edge	5.33	4.67	78	4.2	2	655
Gate	6.4	4.2	37	3.13	3	690
Gin	6.53	3.07	23	6.73	3	640
Golf	5.27	3.27	34	4.53	4	635
Hen	6.93	3.47	22	3.13	3	710
Jail	6.13	3.67	21	3.93	3	720
Knee	6.73	5.07	35	2.53	2	745
Lake	6.6	4.87	54	3.46	3	740
Lock	5.8	4.47	23	3.86	3	773
Nest	6.53	3.53	20	3.2	4	820
Net	6.07	4.07	34	3.53	3	790
Pipe	6.53	3.93	20	4.6	3	770
Plate	6.67	5.4	22	2.27	4	785
Plug	6.4	4.4	23	3.33	4	670
Rain	5.93	5.87	70	2.47	3	790
Ranch	5.73	2	27	5.73	5	910
Tent	6.73	3.6	20	3.87	4	778
Van	6.87	4.2	32	3.47	3	875
Wave	5.27	4.6	46	2.53	3	853
Mean	6.2	4.18	36.54	3.87	3.31	723.46

Table D1. Concrete items used in Experiment Three

	Concrete Rating	Frequency Rating	K-F Frequency	AOA Rating	No. of Phonemes	Item Length (ms)
Aim	2.27	3.87	37	4.87	2	725
Blame	1.93	4.4	34	4.27	4	855
Brave	1.8	3.87	24	3.33	4	805
Calm	2	4.4	35	4.6	3	885
Choose	1.87	4.87	50	3.27	4	945
Cope	1.73	4.13	21	5.27	3	828
Ease	2	3.47	42	5.87	2	815
Glad	1.87	4.87	38	4	4	683
Harm	2.4	4.13	25	4.73	3	760
Hate	2.07	5	42	3.73	3	785
Joy	2.13	4	40	4.07	2	718
Lose	2.6	4.27	58	3.13	3	850
Mad	2.2	4.87	39	4	3	855
Mood	1.27	5.07	37	4.4	3	860
Neat	2.87	4.73	21	3.73	3	848
Nice	1.87	6.27	75	2.33	3	840
Pause	2.93	3.73	21	5	3	808
Pull	3.87	5.33	51	2.73	3	675
Rule	2.47	4.53	73	3.47	3	795
Rush	2.47	4.33	20	3.8	3	760
Save	2.4	4.27	62	4	3	900
Sold	3	4.6	47	4.2	4	983
Trust	1.8	4.33	52	4.33	5	868
Vague	1.4	2.2	25	6.33	3	905
Wise	2.13	2.33	36	4.87	3	945
Worth	2.07	3.8	94	5.13		810
Mean	2.21	4.33	42.27	4.21	3.16	697.69

Table D2. Abstract Items used in Experiment Three

	Wordsmyth Entries	WordNet Senses	Frequency	Concrete	Phonemes	Length
Poach	2	2	17	3.72	3	582
Fudge	2	3	24	6.36	3	588
Prune	2	3	32	6.36	4	549
Stunt	2	2	68	3.44	5	625
Mole	2	6	69	6.2	3	669
Sage	2	5	80	5.88	3	766
Loaf	2	3	95	6.2	3	619
Mint	2	6	102	6.2	4	545
Rash	2	4	184	4.6	3	510
Calf	2	4	186	6.56	3	700
Stern	2	6	220	4.32	4	818
Pine	2	3	242	5.96	3	632
Toast	2	4	260	6.68	4	607
Tense	2	8	315	3.5	4	606
Pen	2	6	348	6.64	3	478
Chap	2	5	387	5.16	3	486
Fleet	3	7	430	4.56	4	714
Port	2	7	486	6.2	3	532
Hide	2	7	576	3.2	3	655
Yard	2	8	637	5.36	3	578
Rare	2	6	895	2	4	492
Page	2	6	1168	6.24	3	684
Tend	2	4	1178	2.24	4	589
Mean	2.04	5	347.78	5.11	3.43	609.74

Table E1. Ambiguous items used in Experiment Four

	Wordsmyth Entries	WordNet Senses	Frequency	Concrete	Phonemes	Length
Winch	1	2	24	5.2	4	544
Growl	1	2	30	4.76	4	585
Hinge	1	3	35	5.92	3	733
Ant	1	2	69	6.64	3	479
Rust	1	7	80	6	3	737
Slot	1	8	88	4.76	4	673
Sip	1	2	89	4.28	4	722
Stain	1	8	127	5.44	3	340
Spy	1	4	150	4.08	4	742
Fog	1	4	168	5.72	4	602
Feast	1	7	218	5.2	3	480
Grin	1	2	228	5.48	4	572
Harsh	1	6	319	2.32	4	909
Soap	1	4	366	6.4	4	717
Crude	1	7	367	2.6	3	472
Silk	1	2	440	6.08	4	593
Bone	1	6	488	6.4	4	737
Loud	1	4	652	3.92	3	420
Shirt	1	2	812	6.56	4	450
Guess	1	6	1073	2.44	3	691
Snow	1	5	1078	6.6	3	596
Farm	1	5	1184	6.56	3	497
Task	1	4	1198	3.48	4	537
Mean	1	4.43	403.61	5.08	3.57	601.22

Table E2. Unambiguous items used in Experiment Four

	Concrete Rating	Frequency Rating	K-F Frequency	AOA Rating	No. of Phonemes	Item Length (ms)
Ash	6.58	4	11	5.25	2	665
Bar	6.07	5.73	82	4.6	2	635
Bomb	6.53	3.27	36	4.6	3	675
Branch	6.5	5.58	33	3.75	6	898
Card	6.13	4.8	26	2.8	3	783
Coat	6.53	5.4	43	2.73	3	798
Cream	6.27	5.27	20	3.4	4	830
Deck	5.6	2.53	23	5.13	3	660
Drug	5.47	4.07	24	5.6	4	645
Edge	5.33	4.67	78	4.2	2	655
Gate	6.4	4.2	37	3.13	3	690
Gin	6.53	3.07	23	6.73	3	640
Golf	5.27	3.27	34	4.53	4	635
Hen	6.93	3.47	22	3.13	3	710
Horn	6.2	3.13	31	3.8	3	730
Jail	6.13	3.67	21	3.93	3	720
Jet	5.2	3.2	29	4.53	3	690
Key	6.83	6.58	88	3.5	2	630
Knee	6.73	5.07	35	2.53	2	745
Lake	6.6	4.87	54	3.46	3	740
Lift	4.53	4.6	23	3.33	4	860
Lock	5.8	4.47	23	3.86	3	773
Map	6.67	5.92	13	4.5	3	730
Moon	6.47	4.8	60	2.47	3	883
Net	6.07	4.07	34	3.53	3	790
Pipe	6.53	3.93	20	4.6	3	770
Plate	6.67	5.4	22	2.27	4	785
Plug	6.4	4.4	23	3.33	4	670
Rake	6.83	4	11	5.33	3	750
Ranch	5.73	2	27	5.73	5	910
Tape	5.8	4.6	35	3.4	3	770
Tent	6.73	3.6	20	3.87	4	778
Van	6.87	4.2	32	3.47	3	875
Wave	5.27	4.6	46	2.53	3	853
Mean	6.18	4.28	33.5	3.93	3.21	746.10

Table F1. Concrete items used in Experiment Five

	Concrete Rating	Frequency Rating	K-F Frequency	AOA Rating	No. of Phonemes	Item Length (ms)
Aim	2.27	3.87	37	4.87	2	725
Bid	2.73	3.4	22	6.2	3	525
Blame	1.93	4.4	34	4.27	4	855
Brave	1.8	3.87	24	3.33	4	805
Calm	2	4.4	35	4.6	3	885
Choose	1.87	4.87	50	3.27	4	945
Cope	1.73	4.13	21	5.27	3	828
Dare	2.17	4.25	21	5.08	2	630
Drop	3.67	4.4	59	3.07	4	740
Ease	2	3.47	42	5.87	2	815
Glad	1.87	4.87	38	4	4	683
Grade	3	3.47	35	5.07	4	818
Halt	2.5	3.75	10	6.58	4	800
Harm	2.4	4.13	25	4.73	3	760
Hate	2.07	5	42	3.73	3	785
Joy	2.13	4	40	4.07	2	718
Lose	2.6	4.27	58	3.13	3	850
Mad	2.2	4.87	39	4	3	855
Mood	1.27	5.07	37	4.4	3	860
Neat	2.87	4.73	21	3.73	3	848
Nice	1.87	6.27	75	2.33	3	840
Pause	2.93	3.73	21	5	3	808
Plea	2.08	3	11	8	3	765
Pull	3.87	5.33	51	2.73	3	675
Rule	2.47	4.53	73	3.47	3	795
Rush	2.47	4.33	20	3.8	3	760
Save	2.4	4.27	62	4	3	900
Slow	2.33	6.25	60	2.5	3	895
Sold	3	4.6	47	4.2	4	983
Teach	3.73	5.27	41	3.47	4	840
Trust	1.8	4.33	52	4.33	5	868
Vague	1.4	2.2	25	6.33	3	905
Wise	2.13	2.33	36	4.87	3	945
Worth	2.07	3.8	94	5.13		810
Mean	2.34	4.31	39.94	4.40	3.21	809.26

Table F2. Abstract items used in Experiment Five

Words	Definitions
Ash	The soft and powdery residue remaining after combustion
Bar	A length of solid material, such as soap or iron
Bomb	A metal shell filled with explosives
Branch	A woody limb that grows out from the body of a tree or shrub
Card	A small piece of thick paper used for messages
Coat	An outer article of clothing with long sleeves, usually worn for added warmth
Cream	The fatty part of the milk, that rises to the top
Deck	The platform or floor that extends from side to side of a ship
Drug	A substance taken to cause a chemical change in the body
Edge	The border or side of an object
Gate	A door in a fence or wall that swings to allow entrance and exit
Gin	A colourless alcoholic liquor, often served with tonic water
Golf	A game in which a ball is struck with clubs into holes on a grassy course
Hen	A female bird, particularly a farmyard animal
Horn	The hard, hollow growth that extends from the head of certain mammals
Jail	A public prison in which offenders are confined
Jet	A high speed aircraft, powered by a backward flow of heated gases
Key	A notched or grooved metal object, used to open doors
Knee	The joint between the upper and lower portions of the human leg
Lake	A large body of water, surrounded on all sides by land
Lift	A compartment used to transport people between the floors of a building
Lock	A device fitted to a door to keep it firmly closed
Map	A printed or drawn representation of a geographic region
Moon	The natural satellite of a planet
Net	An openwork mesh-like material, used for catching things
Pipe	A long hollow cylindrical tube used for conveying gas or liquid
Plate	A flat round dish from which food is served or eaten
Plug	A device with three pins that connects an appliance to an electricity supply
Rake	A long handled garden tool, with a row of teeth at its head
Ranch	A large farm, where cattle are raised on the open range
Tape	A long magnetic strip, used to record sounds and pictures
Tent	A portable shelter made of canvas, nylon, plastic, etc.
Van	A covered vehicle resembling a box-like car, used for transporting people or goods
Wave	One of the many ridges or undulations that move across the surface of the sea

Table G1. Definitions for concrete items used in Experiment Five

Words	Definitions
Aim	To point or direct at a particular person or object
Bid	An offer to buy at a certain price
Blame	To place responsibility for a mistake or fault
Brave	Possessing or displaying courage and resolution
Calm	Free of disturbance or strong feeling
Choose	To select from two or more alternatives
Cope	To deal successfully with problems or responsibilities
Dare	To challenge someone into doing something
Drop	A sudden fall
Ease	Relieve from pain or burden
Glad	To be happy and pleased
Grade	A level, degree, or rank in a scale
Halt	To stop a movement or operation
Harm	To cause damage, hurt, or injury
Hate	A feeling of dislike and hostility
Joy	A feeling of bliss and elation
Lose	To no longer possess something
Mad	Not of sound mind
Mood	A temporary mental or emotional state
Neat	Orderly in appearance, state, or habits
Nice	Pleasantly agreeable and attractive
Pause	To cease an action temporarily
Plea	An earnest request or appeal
Pull	Applying force to pull something toward you
Rule	A code, law, or principle governing conduct
Rush	To hurry, acting swiftly and hastily
Save	To rescue from injury or danger
Slow	Not moving rapidly
Sold	To have exchanged something for money
Teach	To instruct by imparting knowledge
Trust	The confidence or faith placed in someone
Vague	Inexact, unclear, or indistinct
Wise	Having sound understanding and judgement
Worth	Good, valuable, or important enough to warrant something

Table G2. Definitions for abstract items used in Experiment Five

HFLN	Frequency	Neigh. Size	Neigh. Frequency	Concrete	Phonemes	Length
Boat	72	32	67	637	3	590
Book	193	20	67	609	3	520
Face	70	43	61	599	3	610
Game	371	27	66	477		700
Heart	123	20	72	605	3	690
Hope	173	28	68	261	3	520
Job	178	23	62	432	3	540
Kill	238	18	51	386	3	680
Lead	63	38	63	543	3	700
Moon	129	41	64	581	3	700
Park	60	26	68	579	3	800
Rain	94	30	61	600	3	770
Road	197	33	64	583	3	700
Seat	54	41	71	568	3	700
Tone	78	33	65		3	620
Wife	228	19	71	562	3	870
Mean	145.06	29.5	65.06	534.8	3	655.63
HFSN						
Charge	122	8	63		3	650
Death	277	10	60	365	3	580
Faith	111	13	66			630
Food	147	12	62	597	3	605
Guess	56	12	74	247	3	715
House	591	11	61	608	3	685
Jazz	99	6	74		3	730
Judge	49	6	77	506	3	600
Leg	58	12	76	626	3	650
Love	232	12	68	311	3	825
North	207	7	56		3	730
Safe	58	14	62	376	3	780
Sharp	72	7	68		3	735
Song	240	6	67	514	3	750
South	226	6	67	347	3	730
Voice	70	14	63	485	3	660
Mean	163.44	9.75	66.5	452.91	3	704.06

Table H1. High frequency items used in Experiment Six

LFLN	Frequency	Neigh. Size	Neigh. Frequency	Concrete	Phonemes	Length
Bean	5	37	64	604	3	660
Bike	0	25	63		3	670
Cart	5	27	65	576	3	765
Cheat	3	22	68	329	4	720
Fad	2	22	69		3	620
Fin	2	35	62		3	580
Gash	1	20	55			670
Hop	2	25	59	494	3	600
Lard	4	27	68	517	3	800
Mole	4	41	60	590	3	750
Rhyme	3	29	64	434	3	845
Rib	1	20	56	599	3	690
Sage	2	20	67	462	3	870
Shale	0	38	62	458	3	780
Weed	1	33	70	600	3	685
Whim	2	29	72			640
Mean	2.31	28.12	64	514.82	3.07	709.06
LFSN						
Chive	1	10	62		4	870
Fudge	0	9	58	608	3	625
Garb	3	5	57		3	860
Geese	3	9	74	597	3	665
Gong	0	10	88		3	700
Hedge	2	9	65	615	3	670
Keg	2	7	57	586	3	560
Mesh	4	7	71		3	750
Moth	1	10	59	550	3	700
Poise	6	5	60		3	770
Pouch	2	10	56	568	4	810
Sour	3	8	66	458		705
Surf	1	9	61	527	3	835
Torch	2	10	75		4	845
Vase	4	2	57	595	3	850
Verb	4	6	56	337	3	810
Mean	2.38	7.88	63.88	544.1	3.2	751.56

Table H2. Low frequency items used in Experiment Six

Word	Definition
Boat	A small vessel designed for travelling on the surface of the water
Book	A collection of bound paper sheets, containing written or printed words
Face	The front part of the head, extending from the forehead to the chin and from ear to ear
Game	Any competitive activity or sport, played according to rules
Heart	The organ that pumps blood around the body
Hope	A feeling of expectation and desire for something to happen
Job	A regular position of work
Kill	To cause to die
Lead	A strap or cord for restraining or guiding a dog
Moon	The natural satellite of a planet
Park	A large public garden in a town, used for recreation
Rain	Water vapour in the atmosphere that condenses and falls as separate drops from the sky to earth
Road	A long open way with a smooth surface, made for the passage of vehicles
Seat	Furniture designed for sitting on, such as a chair or bench
Tone	The sound of a persons speech, expressing a feeling or mood
Wife	A man's partner in marriage
Charge	To rush forward in attack
Death	The end of life
Food	Any nutritious substance that is eaten to maintain life and growth
Faith	Strong belief in one's religious convictions
Guess	To estimate without enough evidence to be certain
House	A building for human habitation
Jazz	A form of music characterised by improvisation and complex rhythms
Judge	A legally trained public official, who presides over a court
Leg	One of the two limbs that support and transport the human body
Love	Tender and passionate affection
North	The direction in which a compass needle normally points
Safe	Secure from harm or danger
Sharp	Having a thin edge or fine point, especially for cutting or piercing
Song	A short musical composition with words
South	The direction in which birds fly at winter
Voice	The speech sounds produced by the vocal chords uttered through the mouth

Table 11. Definitions of high frequency items used in Experiment Six

Word	Definition
Bean	The hard seed of a coffee or cocoa plant
Bike	A lightweight vehicle, with two wheels and handlebars
Cart	A heavy two-wheeled open vehicle, drawn by a horse, mule, or oxen.
Cheat	To violate rules by deceitful means
Fad	A fashion or behaviour taken up briefly but enthusiastically
Fin	A moveable appendage that fish use for propelling, steering, and balancing
Gash	A long and deep cut, such as a wound
Hop	To jump or skip, on one foot only
Lard	The rendered fat of pigs, used in cooking
Mole	A small, dark, permanent spot or blemish on the skin
Rhyme	A similarity in the sounds at the end of two words or lines of verse
Rib	One of the series of bones that curve from the spine around the chest of a person
Sage	A person honoured as very wise and experienced
Shale	A soft, multi-layered rock that is easily split into sheets
Weed	Any undesirable plant that grows wild
Whim	A sudden odd desire, impulse, or notion
Chive	A small plant, whose long, grass-like leaves are often used as seasoning
Fudge	A small, dense sweet made from sugar, butter, milk, and cream
Garb	Clothes characteristic of a particular profession, way of life, etc.
Geese	Large, long-necked water birds that can be wild or domesticated
Gong	A metallic disk that makes a deep resonant sound when struck with a mallet
Hedge	A solid row of bushes, often used to mark a boundary
Keg	A small cask or barrel
Mesh	A net-like open material, woven together at regular intervals
Moth	A broad-winged chiefly nocturnal insect, with feathery antennae
Poise	The ability to conduct oneself with dignity, composure, and self-possession
Pouch	A small flexible bag used to carry loose substances such as tobacco or letters
Sour	Having a tart or acrid taste
Surf	To ride on the crest of waves towards the shore
Torch	A portable device that produces light
Vase	A ceramic or glass container for displaying flowers
Verb	In grammar, a word that communicates a state of being or an action

Table 12. Definitions for low frequency items used in Experiment Six

References

Allport, D.A. (1984). Auditory-verbal short-term memory and conduction aphasia. In H. Bouma & D.G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 313-325). Hillsdale, NJ: Erlbaum.

Allport, D.A. (1985). Distributed memory, modular sub-systems and dysphasia. In S. Newman and R. Epstein (Eds.). *Current perspectives in dysphasia.* Edinburgh: Churchill Livingstone.

Anderson, J. R. (1983). A spreading activation theory of memory. *Journal of Verbal Learning and Verbal Behavior, 22,* 261-295.

Andrews, S. (1997). The effect of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin and Review, 4 (4),* 439-461.

Astell, A.J., & Harley, T.A. (1996). Tip-of-the-tongue states and lexical access in dementia. *Brain and Language, 54,* 196-215.

Atkinson, R.C., & Shiffrin, R.M. (1968). Human memory: A proposed system and its control processes. In K.W. Spence & J.T. Spence (Eds.), *The psychology of learning and motivation, Vol. 2.,* (pp. 89-195). New York: Academic Press.

Atkinson, R.C., & Shiffrin, R.M. (1971). The control of short-term memory. *Scientific American, 225,* 82-90.

Azuma, T., & Van Orden, G.C. (1997). Why safe is better than fast: The relatedness of a word's meanings affects lexical decision times. *Journal of Memory and Language, 36,* 484-504.

Baars, B.J. (1992). A dozen competing-plans techniques for inducing predictable slips in speech and action. In B.J. Baars (Ed.), *Experimental slips and human error: Exploring the architecture of volition* (pp. 129-150). New York: Plenum Press.

Baddeley, A.D. (1966a). Short-term memory for word sequences as a function of acoustic, semantic, and formal similarity. *Quarterly Journal of Experimental Psychology, 18*, 362-365.

Baddeley, A.D. (1966b). The influence of acoustic and semantic similarity on long-term memory for word sequences. *Quarterly Journal of Experimental Psychology, 18*, 302-309.

Baddeley, A.D. (1986). *Working memory.* Oxford, England: Clarendon Press.

Baddeley, A.D. (1990). *Human memory: Theory and practice.* Needham Heights, Mass.: Allyn and Bacon.

Baddeley, A.D., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105(1)*, 158-173.

Baddeley, A.D., & Hitch, G.J. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation, Vol. 8.* (pp 47-89). New York: Academic Press.

Baddeley, A.D., Lewis, V., & Vallar, G. (1984). Exploring the articulatory loop. *Quarterly Journal of Experimental Psychology, 36A*, 233-252.

Baddeley, A.D., & Scott, D. (1971). Short-term forgetting in the absence of proactive interference. *Quarterly Journal of Experimental Psychology, 23*, 275-283.

Baddeley, A.D., Thomson, N., & Buchanan, M. (1975). Word length and the structure of short-term memory. *Journal of Verbal Learning and Verbal Behaviour, 14*, 575-589.

Badecker, W., Miozzo, M., & Zanuttini, R. (1995). The two-stage model of lexical retrieval: Evidence from a case of anomia with selective preservation of grammatical gender. *Cognition, 57,* 193-216.

Bartram, D. J. (1974). The role of visual and semantic codes in object naming. *Cognitive Psychology, 6,* 325-356.

Borowsky, R., & Masson, M.E.J. (1996). Semantic ambiguity effects in word identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 63-85.

Bourassa, D.C., & Besner, D. (1994). Beyond the articulatory loop: A semantic contribution to serial order recall of supra-span lists. *Psychonomic Bulletin and Review, 1,* 122-125.

Brady, S., Shankweiler, D., & Mann, V. (1983). Speech perception and memory coding in relation to reading ability. *Journal of Experimental Child Psychology, 35,* 345-367.

Bramwell (1897/1984). Illustrative cases of aphasia. *Lancet,* No. 1, 1256-1259 (reprinted in *Cognitive Neuropsychology,* 1249-258).

Bredart, S., & Valentine, T. (1992). From Monroe to Moreau: An analysis of face naming errors. *Cognition, 45,* 187-223.

Broadbent, D.E. (1967). Word-frequency effect and response bias. *Psychological Review, 74,* 1-15.

Broadbent, D.E. (1981). From the percept to the cognitive structure. In J. Long and A.D. Baddeley (Eds.). *Attention and performance IX*. Hillsdale, N.J.: Lawrence Erlbaum Associates.

Brown, A.S. (1991). A review of the tip-of-the-tongue experience. *Psychological Bulletin, 109,* 204-223.

Brown, R., & McNeill, D. (1966). The 'tip of the tongue' phenomenon. *Journal of Verbal Learning and Verbal Behaviour, 5,* 325-337.

Brown, G.D.A., & Hulme, C. (1995). Modelling item length effects in memory span: No rehearsal needed? *Journal of Memory and Language, 34,* 594-621.

Brown, G.D.A., Preece, T., & Hulme, C. (2000). Oscillator-based memory for serial order. *Psychological Review, 107,* 127-181.

Brown, G.D.A., Vousden, J.I., McCormack, T., & Hulme, C. (1999). The development of memory for serial order: A temporal-contextual distinctiveness model. *International Journal of Psychology, 34(5/6),* 389-402.

Brown, J. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology, 10,* 12-21.

Brown, R., & McNeill, D. (1966). The 'tip of the tongue' phenomenon. *Journal of Verbal Learning and Verbal Behaviour, 5,* 325-337.

Burgess, N., & Hitch, G.J. (1992). Toward a network model of the articulatory loop. *Journal of Memory and Language, 31,* 429-460.

Burgess, N., & Hitch, G.J. (1999). Memory for serial order: A network model of the phonological loop and its timing. *Psychological Review, 106 (3),* 551-581.

Burke, D.M., MacKay, D.G., Worthley, J.S., & Wade, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults? *Journal of Memory and Language, 30,* 542-579.

Butterworth, B., Howard, D., & McLoughlin, P. (1984). The semantic deficit in aphasia: The relationship between semantic errors in auditory comprehension and picture naming. *Neuropsychologia, 22,* 409-426.

Caplan, D., Rochon, E., & Waters, G.S. (1992). Articulatory and phonological determinants of word length effects in span tasks. *Quarterly Journal of Experimental Psychology, 45A,* 177-192.

Caramazza, A., Berndt, R.S., & Basili, A.G. The selective impairment of phonological processing: A case study. *Brain and Language, 18,* 128-174.

Caramazza, A., Miceli, G., Villa, G. (1986). The role of the (output) phonological buffer in reading, writing, and repetition. *Cognitive Neuropsychology, 3(1),* 37-76.

Caramazza, A. & Miozzo, M. (1997). The relation between syntactic and phonological knowledge in lexical access: Evidence from the 'tip-of-the-tongue' phenomenon. *Cognition, 64,* 309-343.

Cheung, H., & Wooltorton, L. (2002). Verbal short-term memory as an articulatory system: Evidence from an alternative paradigm. *The Quarterly Journal of Experimental Psychology, 55A (1),* 195-223.

Chi, M.T.H. (1976). Short-term memory limitations in children: Capacity or processing deficit? *Memory and Cognition, 4,* 559-572.

Collins, A., & Loftus, E. (1975). A spreading activation theory of semantic memory. *Psychological Review, 82,* 407-428.

Conrad, R. (1964). Acoustic confusion in immediate memory. *British Journal of Psychology, 55,* 75-84.

Cotton, S., & Grosjean, F. (1984). The gating paradigm: A comparison of successive and individual presentation formats. *Perception and Psychophysics, 35,* 41-48.

Cowan, N. (1992). Verbal memory span and the timing of spoken recall. *Journal of Memory and Language, 31,* 668-684.

Cowan, N., Day, L., Saults, J.S., Keller, T.A., Johnson, T., & Flores, L. (1992). The role of verbal output time on the effects of word length on immediate memory. *Journal of Memory and Language, 31,* 1-17.

Cowan, N., Keller, T.A., Hulme, C, Roodenrys, S.J., McDougall, S., & Rack, J. (1994). Verbal memory span in children: Speech timing clues to the mechanisms underlying age and word length effects. *Journal of Memory and Language, 33,* 234-250.

Cowan, N., Wood, N.L., Wood, P.K., Keller, T.A., Nugent, L.D., & Keller, C.V. (1998). Two separate verbal processing rates contributing to short-term memory span. *Journal of Experimental Psychology, 127(2),* 141-160.

Craig, C.H., & Kim, B. (1990). Effects of time-gating and word length on isolated-word recognition performance. *Journal of Speech and Hearing Research, 33,* 808-815.

Craik, F.I.M., & Lockhart, R.S. (1972). Levels of processing. A framework for memory research. *Journal of Verbal Learning and Verbal Behaviour, 11,* 671-684.

Craik, F.I.M., & Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of Experimental Psychology: General, 104,* 268-294.

Crowder, R.G. (1993). Short-term memory: Where do we stand? *Memory and Cognition, 21,* 142-145.

Cutting, J.C., & Ferreira, V.S. (1999). Semantic and phonological information flow in the production lexicon. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25(2),* 318-344.

Damian, M.F., & Martin, R.C. (1999). Semantic and phonological codes interact in single word production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25(2),* 345-361.

Deese, J. (1959). Influence of inter-item associative strength upon immediate free recall. *Psychological Reports, 5,* 305-312.

Deese, J. (1960). Frequency of usage and the number of words in free recall: The role of association. *Psychological Reports, 7,* 337-344.

de Groot, A.M.B. (1989). Representational aspects of word imageability and frequency as assessed through word associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 824-845.

Dell, G.S. (1986), A spreading-activation theory of retrieval in sentence production. *Psychological Review, 93 (3),* 283-321.

Dell, G.S. (1988). The retrieval of phonological forms in production: Tests of predictions from a connectionist model. *Journal of Memory and Language, 27,* 124-142.

Dell, G.S., & O'Seaghdha, P.G. (1991). Mediated and convergent lexical priming in language production. A Comment on Levelt et al. *Psychological Review, 98,* 604-614.

Dell, G. & P. Reich (1980). Toward a unified theory of slips of the tongue. In V. Fromkin (Ed.), *Errors in linguistic performance: Slips of the tongue, ear, pen, and hand* (pp.273-286). New York: Academic Press.

Dell., G.S., & Reich, P.A. (1981). Stages in sentence production: An analysis of speech error data. *Journal of Verbal Learning and Verbal Behaviour, 20,* 611-629.

Dell, G.S., Schwartz, M.F., Martin, N., Saffran, E.M., & Gagnon, D.A. (1997). Lexical access in aphasic and non-aphasic speakers. *Psychological Review, 104 (4),* 801-838.

DeLosh, E.L., & McDaniel, M.A. (1996). The role of order information in free recall: The role of association. *Journal of Experimental Psychology, Learning, Memory, and Cognition, 22,* 1136-1146.

del Viso, S., Igoa, J., Garcia-Albea, J. (1991). On the autonomy of phonological encoding: Evidence from slips of the tongue in Spanish. *Journal of Psycholinguistic Research, 20,* 161-185.

Dempster, FN (1981). Separate verbal memory and naming deficits in attention deficit disorder and reading disability. *Brain and Language, 31,* 171-184.

Dosher, B.A., & Ma, J-J. (1998). Output loss or rehearsal loop? Output time versus pronunciation limits in immediate recall for forgetting-matched materials. *Journal of Experimental Psychology; Learning, Memory, and Cognition, 24,* 1217-1232.

Egan, J.P. (1948). Articulation testing methods. *Laryngoscope, 58,* 955-991.

Estes, W.K. (1973). Phonemic coding and rehearsal in short-term memory. *Journal of Verbal Learning and Verbal Behaviour, 12,* 360-372.

Eysenck, M.W. (1978). Verbal remembering. In B.M. Foss (Ed.), *Psychology Survey, No. 1,* (pp.32-42). London: Allen & Urwin.

Fallon, A.B., Groves, K., & Tehan, G. (1999). Phonological similarity and trace degradation in the serial recall task: When CAT helps RAT, but not MAN. *International Journal of Psychology, 34(5/6),* 301-307.

Farrell, S., & Lewandowsky, S. (in press). An endogenous distributed model of ordering in serial recall. *Psychonomic Bulletin & Review.*

Forster, K.I. (1976). Accessing the mental lexicon. In R.J. Wales and E. Walker (Eds.). *New approaches to language mechanisms* (pp. 257-287). Amsterdam: North-Holland.

Forster, K.L. & Chambers, S.M. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behaviour, 12,* 627-635.

Galton, F. (1883). *Enquiries into human faculty and its development.* London: MacMillan.

Gaskell, M.G., & Marslen-Wilson, W.D. (1997). Integrating form and meaning: A distributed model of speech perception. *Language and Cognitive Processes, 12,* 613-656.

Gathercole, S.E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory and Cognition, 23,* 83-94.

Gathercole, S.E., & Baddeley, A.D. (1993). *Working memory and language.* Hove, U.K.: Lawrence Erlbaum Associates Ltd.

Gathercole, S.E., & Adams, A.M. (1993). Phonological working memory in very young children. *Developmental Psychology, 29(4),* 770-778.

Gathercole, S.E., Frankish, C.R., Pickering, S.J., & Peaker, S.M. (1999). Phonotactic influences on short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 1-13.

Gathercole, S.E., & Hitch, G.J. (1993). Developmental changes in short-term memory: A revised working memory perspective. In A.F. Collins, S.E. Gathercole, M.A. Conway, & P.E. Morris (Eds.), *Theories of memory* (pp. 189-209). Hove: Lawrence Erlbaum Associates.

Gathercole, S.E., Hitch, G.J., Service, E. & Martin, A.J. (1997). Phonological short-term memory and new word learning in children. *Developmental Psychology., 33,* 966–979.

Gathercole, S.E., & Martin, A.J. (1996). Interactive processes in phonological memory. In S.E. Gathercole (Ed.), *Models of Short-Term Memory.* Psychology Press: Hove, UK.

Gathercole, S.E., Pickering, S.J., Hall, N., & Peaker, S.M. (2001). Dissociable lexical and phonological influences on serial recognition and serial recall. *Quarterly Journal of Experimental Psychology, 54A(1),* 1-30.

Gathercole, S.E., Willis, C., Emslie, H., & Baddeley, A.D. (1991). The influence of syllables and wordlikeness on children's repetition of nonwords. *Applied Psycholinguistics, 12,* 349-367.

Gipson, P. (1986). The production of phonology and auditory priming. *British Journal of Psychology, 77,* 359-375.

Goldinger, S.D. (1996). Auditory Lexical Decision. *Language and Cognitive Processes, 11 (6),* 559-567.

Gordon, J. K., & Dell., G.S. (2001). Phonological neighborhood effects: Evidence from aphasia and connectionist modelling. *Brain and Language, 79,* 21-23.

Gordon, J.K., & Meyer, D.E. (1984). Perceptual-motor processing of phonetic features. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 153-178.

Gregg, V.H., Freedman, C.M., & Smith, D.K. (1989). Word frequency, articulatory suppression, and memory span. *British Journal of Psychology, 80,* 363-374.

Griffin, Z.M., & Bock, K. (1998). Constraint, word frequency, and the relationship between lexical processing levels in spoken word production. *Journal of Memory and Language, 38,* 313-338.

Grosjean, F. (1980). Spoken word recognition processes and the gating paradigm. *Perception and Psychophysics, 28,* 267-283.

Gupta, P., & MacWhinney, B. (1997). Vocabulary acquisition and verbal short-term memory: Computational and neural bases. *Brain and Language, 59,* 267-333.

Haarman, H., & Usher, M. (2001). Maintenance of semantic information in capacity-limited item short-term memory. *Psychonomic Bulletin and Review, 8 (3),* 568-578.

Hanley, J.R., & Kay, J. (1997). An effect of imageability on the production of phonological errors in auditory repetition. *Cognitive Neuropsychology, 14,* 1065-1084.

Hanley, J.R., Kay, J., & Edwards, M. (2002). Imageability effects, phonological errors, and the relationship between auditory repetition and picture naming: Implications for models of auditory repetition. *Cognitive Neuropsychology, 19 (3),* 193-206.

Harley, T.A. (1984). A critique of top-down independent levels models of speech production: Evidence from non-plan-internal speech errors. *Cognitive Science, 8,* 191-219.

Harley, T A., & Bown, H. E. (1998). What causes a tip-of-the-tongue state? Evidence for lexical neighbourhood effects in speech production. *British Journal of Psychology, 89,* 151-174.

Hawley, M. (Ed.). (1977). *Benchmark papers in acoustics: Vol. 11: Speech intelligibility and speaker recognition.* Stroudsberg, PA: Dowden, Hutchinson, and Ross.

Hebb, D.O. (1961). Distinctive features of learning in the higher animal. In J.F. Delafresnaye (Ed.), *Brain mechanisms and learning.* (pp. 37-46). London: Oxford University Press.

Hino, Y., & Lupker, S.J. (1996). Effects of polysemy in lexical decision and naming: An alternative to lexical access accounts. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 1331-1356.

Hinton, G.E., & Shallice, T. (1991). Lesioning an attractor network: Investigations of acquired dyslexia. *Psychological Review, 98,* 74-95.

Hitch, G.J. (1978). The role of short-term working memory in mental arithmetic. *Cognitive Psychology, 10,* 302-323.

Hitch, G.J. (1980). Developing the concept of working memory. In G. Claxon (Ed.), *Cognitive psychology: New directions,* (pp.154-196). London: Routledge & Kegan Paul.

Hotopf, W.H.N. (1980). Semantic similarity as a factor in whole-word slips of the tongue. In V.A. Fromkin (Ed.), *Errors in linguistic performance: Slips of the tongue, ear, pen, and hand,* (pp.97-110). New York: Academic Press.

Houghton, G. (1990). The problem of serial order: A neural network model of sequence learning and recall. In R. Dale, C. Mellish, & M. Zock (Eds.), *Current research in natural language generation,* (pp. 287-319). London: Academic Press.

Houghton, G., & Hartley, T. (1996). Parallel models of serial behaviour: Lashley revisited. *Psyche, 2 (25).*

Howard, D., & Franklin, S.E. (1988). *Missing the meaning?* Cambridge, MA: MIT Press.

Howard, D., & Franklin, S.E. (1990). Memory without rehearsal. In G. Vallar and T. Shallice (Eds.). *Neuropsychological impairments of short-term memory* (pp. 287-318). Cambridge, UK: Cambridge University Press.

Howes, D.H. (1957). On the relation between the intelligibility and occurrence of English words. *Journal of the Acoustical Society of America, 29,* 296-305.

Hulme, C., Maughan, S., & Brown, G.D.A. (1991). Memory for familiar and unfamiliar words: evidence for a long-term memory contribution to short-term memory span. *Journal of Memory and Language, 30,* 685-701.

Hulme, C., Newton, P., Cowan, N., Stuart, G., & Brown, G.D.A. (1999). Think before you speak: Pauses, memory search, and trace redintegration processes in verbal memory span. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25(2),* 447-463.

Hulme, C., Roodenrys, S., Brown, G.D.A., & Mercer, R. (1995). The role of long-term memory mechanisms in memory span. *British Journal of Psychology, 86,* 527-536.

Hulme, C., Roodenrys, S., Schweickert, R., Brown, G.D.A., Martin, S., & Stuart, G. (1997). Word-frequency effects on short-term memory tasks: Evidence for a redintegration process in immediate serial recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23(5),* 1217-1232.

Hulme, C., Thomson, N., Muir, C., & Lawrence, A. (1984). Speech rate and the development of short-term memory. *Journal of Experimental Child Psychology, 38,* 241-253.

Humphreys, G.W., Riddoch, M.J. & Quinlan, P.T. (1988). Cascade proceses in picture identification. *Cognitive Neuropsychology, 5,* 67-103

Hunter, I.M.L. (1964). *Memory.* London: Penguin.

Huttenlocher, J., & Kubicek, L. F. (1983). The source of relatedness effects on naming latency. *Journal of Experimental Psychology: Learning, Memory and Cognition, 9,* 486-496.

Huttenlocher, J., & Newcombe, N. (1976). Semantic effects on ordered recall. *Journal of Verbal Learning and Verbal Behaviour, 15,* 387-399.

Jacobs, J. (1887). Experiments on 'prehension'. *Mind, 12,* 75-79.

James, W. (1890). *Principles of Psychology.* New York: Henry Holt.

Jescheniak, J.D., & Levelt, W.J.M. (1994). Word frequency effects in speech production: Retrieval of syntactic information and of phonological form. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 824-843.

Jescheniak, J.D., & Schriefers, H.J. (1998). Serial versus cascaded processing in lexical access in language production: Further evidence from the coactivation of near-synonyms. *Journal of Experimental Psychology: Learning, Memory and Cognition, 24 (5),* 1256-1274.

Jones, D.M. (1990). Recent advances in the study of human performance in noise. *Environment International, 16,* 447-458.

Jones, D.M. (1993). Objects, streams and threads of auditory attention. In A.D. Baddeley, L. Weiskrantz, & D.E. Broadbent (Eds.), *Attention: Selection, awareness, and control: A tribute to Donald Broadbent* (pp. 87-104). Oxford: Oxford University Press.

Jones, D.M. (1994). Disruption of memory for lip-read lists by irrelevant speech: Further support for the changing state hypothesis. *Quarterly Journal of Experimental Psychology, 47a,* 143-160.

Jones, D.M., Beaman, C.P., & Macken, W.J. (1996). The object-orientated episodic recall model. In S. Gathercole (Ed.), *Models of short-term memory* (pp. 209-238). Hove: Psychology Press.

Jones, D.M., & Macken, W.J. (1993). Irrelevant tones produce an "irrelevant speech effect": Implications for phonological coding in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 369-381.

Jones, D.M., Madden, C., & Miles, C. (1992). Privileged access by irrelevant speech to short-term memory: The role of changing state. *Quarterly Journal of Experimental Psychology, 44a,* 645-669.

Jones, G.V. (1985). Deep dyslexia, imageability, and ease of predication. *Brain and Language, 24,* 1-19.

Joordens, S., & Besner, D. (1994). When banking on meaning is not (yet) money in the bank: Explorations in connectionist modelling. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 1051-1062.

Kawamoto, A.H. (1993). Nonlinear dynamics in the resolution of lexical ambiguity: A parallel distributed processing account. *Journal of Memory and Language, 32,* 474-516.

Kay, J., and A. W. Ellis. (1987). A cognitive neuropsychological case study of anomia: Implications for psychological models of word retrieval. *Brain, 110,* 613-629.

Kellas, G., Ferraro, F.R., & Simpson, G.B. (1988). Lexical ambiguity and the time-course of attentional allocation in word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 601-609.

Kempen, G., & Huijbers, P. (1983). The lexicalisation process in sentence production and naming: Indirect election of words. *Cognition, 14,* 185-209.

Keppel, G., & Underwood, B.J. (1962). Proactive inhibition in short-term retention of single items. *Journal of Verbal Learning and Verbal Behaviour, 1,* 153-161.

Klatt, D.H. (1980). Speech perception: A model of acoustic-phonetic analysis and lexical access. In R.A. Cole (Ed.), *Perception and production of fluent speech.* (pp.243-288). Hillsdale, NJ: Lawrence Erlbaum Associates.

Klein, D.E.., & Murphy, G.L. (2001). The representation of polysemous words. *Journal of Memory and Language, 45,* 259-282.

Knott, R., Patterson, K., & Hodges, J.R. (2000). The role of speech production in auditory-verbal short-term memory: Evidence from progressive fluent aphasia. *Neuropsychologia, 38,* 125-142.

Kohn, S.E., & Friedman, R.B. (1986). Word meaning deafness: A phonological-semantic dissociation. *Cognitive Neuropsychology, 3,* 291-308.

Kroll, J.F., & Merves, J.S. (1986). Lexical access for concrete and abstract words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 92-102.

Kucera, H., & Francis, W.N. (1967). *Computational analysis of present-day American English.* Providence, RI: Brown University Press.

Landauer, T.K., & Streeter, L. (1973). Structural differences between common and rare words: Failure of equivalence assumptions for theories of word recognition. *Journal of Verbal Learning and Verbal Behaviour, 12,* 119-131.

Levelt, W.J.M. (1989). *Speaking: From intention to articulation.* Cambridge, MA. MIT Press.

Levelt, W.J.M., Roelofs, A., & Meyer, A.S. (1999). A theory of lexical access in speech production. *Behaviour and Brain Sciences, 22,* 1-75.

Levelt, W.J.M., Schriefers, H., Vorberg, D., Meyer, A.S., Pechmann, T., & Havinga, J. (1991). The time course of lexical access in speech production: A study of picture naming. *Psychological Review, 98,* 122-142.

Levy, B.A. (1971). The role of articulation in auditory and visual short-term memory. *Journal of Verbal Learning and Verbal Behaviour, 10,* 123-132.

Lewandosky, S. (1999). Redintegration and response suppression in serial recall: A dynamic network model. *International Journal of Psychology, 34(5/6),* 434-446.

Liberman, A.M., Cooper, F.S., Shankweiler, D.P., & Studdert-Kennedy, M. (1967). Perception of the speech code. *Psychological Review, 74,* 431-461.

Lichacz, F.M., Herdman, C.M., Lefevre, J., & Baird, B. (1999). Short report: Polysemy effects in word naming. *Canadian Journal of Experimental Psychology, 53(2),* 189-193.

Loess, H. (1968). Short-term memory and item similarity. *Journal of Verbal learning and Verbal Behaviour, 7,* 87-92.

Longoni, A.M., Richardson, J.T.E., & Aiello, A. (1993). Articulatory rehearsal and phonological storage in working memory. *Memory and Cognition, 21,* 11-22.

Lorch, R.F., & Myers, J.L. (1990). Regression analysis of repeated measures data in cognitive research. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16 (1),* 149-157.

Luce, P.A. (1986). *Neighborhoods of words in the mental lexicon.* Doctoral Dissertation, Indiana University, Bloomington, IN.

Luce, P.A., & Pisoni, D.B. (1998). Recognising spoken words: The neighbourhood activation model. *Ear and Hearing, 19,* 1-36.

Luce, P.A., Pisoni, D.B., & Goldinger, S.D. (1990). Similarity neighborhoods of spoken words. In G.T.A. Altmann (Ed.), *Cognitive models of speech processing,* (pp. 122-147). Cambridge, MA: MIT Press.

MacKay, D.G. (1987). *The organisation of perception and action: A theory for language and other cognitive skills.* New York: Springer-Verlag.

Mandler, G. (1980). Recognising: The judgement of previous occurrence. *Psychological Review, 87,* 252-271.

Marslen-Wilson, W.D. (1987). Functional parallelism in spoken word recognition. In U.H. Frauenfelder & L.K. Tyler (Eds.). *Spoken word recognition.* Cambridge, MA: MIT Press.

Marslen-Wilson, W.D. (1990). Activation, competition, and frequency in lexical access. In G.T.M Altmann (Ed.). *Cognitive models of speech processing: Psycholinguistic and computational perspectives.* Cambridge, MA: MIT Press.

Marslen-Wilson, W.D., & Warren, P. (1994). Levels of perceptual representation and process in lexical access: Words, phonemes, and features. *Psychological Review, 101,* 653-675.

Marslen-Wilson, W.D., & Zwisterlood, P. (1989). Accessing spoken words: The importance of word onsets. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 576-585.

Martin, N., & Saffran, E.M. (1990). Repetition and verbal STM in transcortical sensory aphasia: A case study. *Brain and Language, 39,* 254-288.

Martin, N., Saffran, E.M., & Dell, G.S. (1996). Recovery in deep dyslexia: evidence for a relation between auditory-verbal STM capacity and lexical errors in repetition. *Brain & Language, 52,* 83-113.

Martin, N., Weisberg, R.W., & Saffran, E.M. (1989). Variables influencing the occurrence of naming errors: Implications for models of lexical retrieval. *Journal of Memory and Language, 28,* 462-485.

Martin, R.C., & Lesch, M.F. (1996). Associations and dissociations between language impairment and list recall: Implications for models of STM. In S.E. Gathercole (Ed.). *Models of short-term memory* (pp. 149-178). East Sussex, UK: Psychology Press.

Martin, R.C., Lesch, M.F., & Bartha, M.C. (1999). Independence of input and output phonology in word processing and short-term memory. *Journal of Memory & Language, 41,* 3-29.

Martin, R.C., & Romani, C. (1994). Verbal working memory and sentence comprehension: A multiple components view. *Neuropsychology, 8,* 506-523.

May, R.B., Cuddy, L.J., & Norton, J.M. (1979). Temporal contrast and the word frequency effect. *Canadian Journal of Psychology, 33,* 141-147.

McCarthy, R., & Warrington, E.K. (1984). A two-route model of speech production: Evidence from aphasia. *Brain, 107,* 463-485.

McClelland, J.L., & Elman, J.L. (1986). The TRACE model of speech perception. *Cognitive Psychology, 18,* 1-86.

McLeod, P., & Posner, M. (1984). Priviledged loops from percept to act. In H. Bouma & D.G. Bouhuis (Eds.). *Attention and performance* X. London: Erlbaum.

Mechanic A. (1964). The responses involved in the rote learning of verbal materials. *Journal of Verbal learning and Verbal Behaviour, 3,* 30-36.

Melton, A.W. (1963). Implications of short-term memory for a general theory of memory. *Journal of Verbal learning and Verbal Behaviour, 2,* 1-21.

Michas, I.C., & Henry, L.A. (1994). The link between phonological memory and vocabulary acquisition. *British Journal of Developmental Psychology, 12,* 147-164.

Miller, G.A. (1956). The magical number seven plus or minus two: Some limits in our capacity for processing information. *Psychological Review, 63,* 81-97.

Miller, G.A. (1990). WordNet: An on-line lexical database. *International Journal of Lexicography,* 3, 235-312.

Miller, G.A., & Fellbaum, C. (1991). Semantic networks of English. *Lexical and Conceptual Semantics, Cognition Special Issue,* 197-222.

Millis, M.L., & Button, S.B. (1989). The effect of polysemy on lexical decision time: Now you see it, now you don't. *Memory and Cognition, 17,* 141-147.

Miozzo, M., & Caramazza, A. (1997). Retrieval of lexical-syntactic features in tip-of-the-tongue states. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23 (6),* 1410-1423.

Monsell, S. (1984). Components of working memory underlying verbal skills: A "distributed capacities" view – A tutorial review. In H. Bouma & D.G. Bouwhis (Eds.). *Attention and performance X* (pp. 327-350). London: Erlbaum.

Monsell, S. (1987). On the relation between lexical input and output pathways for speech. In A. Allport, D.G. MacKay, W. Prinz, & E. Scheerer (Eds.), *Language perception and production: Relationships between listening, speaking, reading, and writing* (pp. 273-311). London: Academic Press.

Monsell, S., & Banich, M.T. (1982). Lexical priming: Repetition effects across input and output modalities. Paper presented at the 23rd Annual Meeting of the Psychonomic Society, Minneapolis, MN. 13 November, 1982.

Morton, J. (1969). Interaction of information in word recognition. *Psychological Review, 76,* 165-178.

Moss, H.E., & Gaskell, M.G. (2000). Lexical semantic processing during speech. In S. Garrod and M. Pickering (Eds.). *Language processing* (pp. 59-100). Hove, UK: Psychology Press.

Motley, M.T., & Baars, B.J. (1976). Laboratory inducement of verbal slips: A new method for psycholinguistic research. *Communication Quarterly, 24,* 28-34.

Murdock, B.B., Jr. (1976). Item and order information in short-term serial memory. *Journal of Experimental Psychology: General, **10**,* 191-216.

Nairne, J.S. (1988). A framework for interpreting recency effects in immediate serial recall. *Memory and Cognition, 16,* 343-352.

Nairne, J.S. (1990). A feature model of immediate memory. *Memory and Cognition, 18,* 251-269.

Nation, K., Adams, J. W., Bowyer-Crane, C. A., & Snowling, M. J. (1999). Working memory deficits in poor comprehenders reflect underlying language impairments. *Journal of Experimental Child Psychology, 73 (2),* 139-158.

Naveh-Benjamin, M., & Ayres, T.J. (1986). Digit span, reading rate, and linguistic relativity. *Quarterly Journal of Experimental Psychology, 38A,* 739-751.

Neath, I., & Nairne, J.S. (1995). Word length effects in immediate memory: Overwriting trace decay theory. *Psychonomic Bulletin & Review,* 2, 429-441.

Nelson, T.O. (1977). Repetition and depth of processing. *Journal of Verbal learning and Verbal Behaviour, 16,* 151-172.

Newton, P.K., & Barry, C. (1997). Concreteness effects in word production but not word comprehension in deep dyslexia. *Cognitive Neuropsychology, 14 (4),* 481-509.

Nickels, L., & Howard, D. (1995). Phonological errors in aphasic naming: Comprehension, monitoring, and lexicality. *Cortex, 31,* 209-237.

Nolan, C. (Writer/Director). (2000). *Memento* (Motion picture). United States.

Norris, D., McQueen, J.M., & Cutler, A. (2000). Merging information in speech recognition: Feedback is never necessary. *Brain and Behavioural Sciences, 23,* 299-370.

Oldfield, R.C., & Wingfield, A. (1965). Response latencies in naming objects. *Quarterly Journal of Experimental Psychology, 17,* 273-281.

Owens, E. (1961). Intelligibility of words varying in familiarity. *Journal of Speech and Hearing Research, 4,* 113-129.

Paivio, A.U. (1986). *Mental representations: A dual coding approach.* New York: Oxford University Press.

Palmer, M. (2000). Consistent criteria for sense distinctions. *Computers and the Humanities, 34,* 217-222.

Papagno, C., Valentine, T. & Baddeley, A.D. (1991). Phonological short-term memory and foreign-language vocabulary learning. *Journal of Memory and Language, 30,* 331-347.

Papagno, C. & Vallar, G. (1992) Phonological short-term memory and the learning of novel words: The effects of phonological similarity and item length. *Quarterly Journal of Experimental Psychology 44a,* 44-67.

Patterson, K., Graham, N., & Hodges, J.R. (1994). The impact of semantic memory loss on phonological representations. *Journal of Cognitive Neuroscience, 6,* 57-69.

Peterson, L.R., & Peterson, M.J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology, 58,* 193-198.

Plaut, D.C. (1997). Structure and function in the lexical system: insights from distributed models of word reading and lexical decision. *Language and Cognitive Processes, 12 (5/6),* 765-805.

Plaut, D.C., & Shallice, T. (1993). Deep dyslexia: A case study of connectionist neuropsychology. *Cognitive Neuropsychology, 10,* 377-500.

Poirier, M., & Saint-Aubin, J. (1995). Memory for related and unrelated words: Further evidence on the influence of semantic factors in immediate serial recall. *Quarterly Journal of Experimental Psychology, 48a,* 384-404.

Poirier, M., & Saint-Aubin, J. (1996). Immediate serial recall, word frequency, item identity, and item position. *Canadian Journal of Experimental Psychology, 50,* 408-412.

Postman, L. (1975). Verbal learning and memory. *Annual Review of Psychology, 26,* 291-335.

Puckett, J.M., & Kausler, D.H. (1984). Individual differences and models of memory span: A role for memory search rate? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 72-82.

Rastle, K., & Davis. M.H. (2002). On the complexities of measuring naming. *Journal of Experimental Psychology: Human Perception and Performance, 28 (2),* 307-314.

Rodd, J., Gaskell, M.D., & Marslen-Wilson, W.D. (2000). Effects of semantic ambiguity in spoken word recognition. Proceedings of Spoken Word Access Processes, Nijmegen, The Netherlands. May 2000.

Rodd, J., Gaskell, M.D., & Marslen-Wilson, W.D. (2002). Making sense of ambiguity: Semantic competition in lexical access. *Journal of Memory and Language, 46,* 245-266.

Rosenzweig, M.R., & Postman, L. (1957). Intelligibility as a function of frequency of usage. *Journal of Experimental Psychology, 54,* 412-422.

Roodenrys, S., Hulme, C., Alban, J., Ellis, A., & Brown, G.D.A. (1994). Effects of word frequency and age of acquisition on short-term memory span. *Memory and Cognition, 22,* 695-701.

Roodenrys, S., Hulme, C., & Brown, G.D.A. (1993). The development of short-term memory span: Separable effects of speech rate and long-term memory. *Journal of Experimental Child Psychology, 56,* 431-442.

Roodenrys, S., Hulme, C., Lethbridge, A., Hinton, M., & Nimmo, L.M. (in press). Word frequency and phonological neighborhood effects on verbal short-term memory. *Journal of Experimental Psychology: Learning, Memory & Cognition.*

Rueckl, J.G. (1995). Ambiguity and connectionist networks – still settling into a solution – comment. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 501-508.

Rumelhart, D.E., Lindsay, P.H., & Norman, D.A. (1972). A process model for long-term memory. In E. Tulving & W. Donaldson (Eds.), *Organisation of memory,* (pp. 198-248). New York: Academic Press.

Saffran, E.J., & Schwartz, M.F. (1994). Of cabbages and things: Semantic memory from a neuropsychological point of view: A tutorial review. *Attention and Performance, 15,* 507-536.

Saint-Aubin, J., & Poirier, M. (1999). The influence of long-term memory factors on immediate serial recall: An item and order analysis. *International Journal of Psychology, 34,* 347-352.

Saint-Aubin, J., & Poirier, M. (2000). Immediate serial recall of words and nonwords: Tests of the retrieval-based hypothesis. *Psychonomic Bulletin & Review, 7(2),* 332-340.

Salame, P., & Baddeley, A.D. (1982). Disruption of short-term memory by unattended speech: Implications for the structure of working memory. *Journal of Verbal Learning and Verbal Behaviour, 21,* 150-164.

Salasoo, A., & Pisoni, D. B. (1985). Interaction of knowledge sources in spoken word identification. *Journal of Memory and Language, 24,* 210-231.

Savin, H.B. (1963). Word-frequency effect and errors in the perception of speech. *Journal of the Acoustical Society of America, 35,* 200-206.

Scarborough, D.L., Cortese, C., & Scarborough, H.S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 1-17.

Schneider, W., & Shiffrin, R.M. (1977). Controlled and automatic information processing: I. Detection, search, and attention. *Psychological Review, 84,* 1-66.

Schriefers, H., Meyer, A.S., & Levelt, W.J.M. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of Memory and Language, 29,* 86-102.

Schwanenflugel, P.J., Harnishfeger, K.K., & Stowe, R.W. (1988). Context availability and lexical decision for abstract and concrete words. *Journal of Memory and Language, 27,* 499-520.

Schweickert, R. (1993). A multinomial processing tree model for degradation and redintegration in immediate serial recall. *Memory and Cognition, 21,* 167-175.

Schweickert, R., & Boruff, B. (1986). Short-term memory capacity: Magic number or magic spell? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 419-425.

Schweickert, R., Chen, S., & Poirier, M. (1999). Redintegration and the useful lifetime of the verbal memory representation. *International Journal of Psychology, 34 (5/6),* 447-453.

Schweickert, R., Hayt, C., Hersberger, L., & Guentert, L. (1996). How many words can be held in working memory? A model and a method. In S. Gathercole (Ed.), *Models of short-term memory.* Hove, UK: Lawrence Erlbaum Associates Ltd.

Service, E. (1998). The effect of word length on immediate serial recall depends on phonological complexity, not articulatory duration. *Quarterly Journal of Experimental Psychology, 51A,* 283-304.

Service, E. (2000). Phonological complexity and word duration in immediate recall: Different paradigms answer different questions. A comment on Cowan, Nugent, Elliott, and Geer. *Quarterly Journal of Experimental Psychology, 53A (3),* 661-665.

Shallice, T., McLeod, P., & Lewis, K. (1985). Isolating cognitive models with the dual-task paradigm: Are speech perception and speech production separate processes? *Quarterly Journal of Experimental Psychology, 37a,* 507-532.

Slowiaczek, L.M., & Pisoni, D.B. (1986). Effects of phonological similarity on priming in auditory lexical decision. *Memory and Cognition, 14,* 230-237.

Smith, S.M. (1994). Frustrated feelings of imminence: On the tip-of-the-tongue. In J. Metcalfe & A. Shimamura (Eds.) *Metacognition: Knowing about knowing,* (pp. 27-45). Cambridge, MA: MIT Press.

Sternberg, S. (1966). High-speed scanning in human memory. *Science, 153,* 652-654.

Strain, E., Patterson, K.E., and Seidenberg, M.S., (1995). Semantic influences on word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition , 21,* 1140-1154.

Stuart, G. & Hulme, C., (2000). The effects of word co-occurrence on short-term memory: Associative links in long-term memory affect short-term memory performance. *Journal of Experimental Psychology: Learning, Memory and Cognition, 26(3),* 1-7.

Taft, M., & Hambly, G. (1986). Exploring the cohort model of spoken word recognition. *Cognition, 22,* 259-282.

Tehan, G., & Humphreys, M.S. (1988). Articulatory loop explanations of memory span and pronunciation rate correspondences: A cautionary note. *Bulletin of the Psychonomic Society, 26,* 293-296.

Treisman, M. (1978). Space or lexicon? The word frequency effect and the error response frequency effect. *Journal of Verbal Learning and Verbal Behaviour, 17,* 37-59.

Treisman, M., Cook, N., Naish, P.L.N., & McCrone, J.K. (1994). The internal clock: Electroencephalographic evidence for oscillatory processes underlying time perception. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 47a,* 241-289.

Tyler, L.K., Voice, K., & Moss, H.E. (2000). The interaction of meaning and sound in spoken word recognition. *Psychonomic Bulletin and Review, 7 (2),* 320-326.

van der Lely, H. K. J., & Howard, D. (1993). Specifically language impaired children: Linguistic impairment or short term memory deficit? *Journal of Speech and Hearing Research, 37,* 1193-1207.

Vigliocco, G., Antonini, T. & Garrett, M. F. (1997). Grammatical gender is on the tip of Italian tongues. *Psychological Science, 8,* 314-317.

Vitevitch, M.S. (2002). The influence of phonological similarity neighborhoods on speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28 (4),* 737-747.

Walker, I., & Hulme, C. (1999). Concrete words are easier to recall than abstract words: Evidence for a semantic contribution to short-term serial recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25(5),* 1-16.

Walley, A., Michela, V., & Wood, D. (1995). The gating paradigm: Effects of presentation format on spoken word recognition by children and adults. *Perception and Psychophysics, 57,* 343–351.

Warrington, E.K.(1975). The selective impairment of semantic memory. *Quarterly Journal of Experimental Psychology, 27,* 635-657.

Watkins, M.J. (1977). The intricacy of memory span. *Memory and Cognition, 5,* 529-534.

Waugh, N.C. (1970). On the effective duration of a repeated word. . *Journal of Verbal Learning and Verbal Behaviour, 9,* 587-595.

Wetherick, N.E. (1975). The role of semantic information in short-term memory. *Journal of Verbal Learning and Verbal Behaviour, 14,* 471-480.

Wickelgren, W.A. (1965). Short-term memory for phonologically similar lists. *American Journal of Psychology, 78,* 567-574.

Wright, C.C. (1979). Duration differences between rare and common words and their implications for the interpretation of word frequency effects. *Memory and Cognition, 7,* 411-419.

Zwitserlood, P. (1989). The locus of the effects of sentential-semantic context in spoken-word processing. *Cognition, 32,* 25-64.