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**Some Observations on Working Memory Tasks
and Issues in Cognitive Psychology¹**

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Some Observations on Working Memory Tasks and Issues in Cognitive Psychology

Abstract. This paper reviews a variety of experimental paradigms that have been used in the study of working memory. Special emphasis is placed on issues that are relevant to language processing and comprehension. The first section describes the features and procedures of simple and complex span measures. The demand characteristics of these tasks and their implications for task performance are examined. The second section looks at experimental issues such as the use of closed and open sets of items in the memory span task, and the relevance of findings such as the phonological similarity effect and the word length effect on the nature of representation in working memory. The final section explores general theoretical issues that have emerged since the Baddeley and Hitch (1974) model of working memory. Directions for future research are discussed.

Introduction

The motivation for this review is to comment on some of the major issues that have evolved in the course of 25 years' research in the field of "working memory" (hereafter WM) since the seminal paper of Baddeley and Hitch (1974), which first postulated their now famous WM model. This model has three components: 1) a central executive, 2) the phonological loop, and 3) the visuo-spatial sketchpad. The central executive is an attentional system that controls and supervises the two subsidiary slave systems, the phonological loop and the visuo-spatial sketchpad. The visuo-spatial sketchpad is responsible for storing and manipulating visual images in WM, whereas the phonological loop handles speech-based information.

The phonological loop of WM has received the most attention from researchers and is currently the most developed component of the model (Baddeley, 1998). The loop consists of a passive phonological store and an articulatory rehearsal mechanism based on inner speech. WM traces held in the phonological store are assumed to fade after about 2 seconds unless they can be refreshed by subvocal rehearsal operations, which serve to maintain the integrity of the traces in the store. These rehearsal processes are also thought to be capable of converting written information into a phonological code and registering it in the store. This component of WM is thought to be important in language comprehension and may play role in learning new words (Baddeley, Gathercole, & Papagno, 1998).

Attempting to integrate *all* aspects of a quarter-century of work on WM would lead to a gargantuan tome, given that the topic is relevant to many fields within cognitive science. Rather, I have decided to concentrate only on those findings that might be relevant to language processing and comprehension. For the most part, the focus will be on selected papers from experimental psychology, supplemented by clinical findings where relevant. Language acquisition and developmental issues will be addressed at a later time.

This review is divided into three parts. I will begin by discussing the various WM tasks that have been employed by experimental psychologists and attempt a component analysis of these tasks. Part 2 will examine experimental issues and findings. Issues such as the nature of the items used in WM tasks, the nature of the WM code or trace, and the influence of long-term memory (LTM) on WM will be examined. I will then end with a discussion of general theoretical issues such as whether WM is separate from LTM and whether there are multiple WMs.

I. Working Memory Tasks

Simple Span Tasks

These tasks are called “simple” because they are not as cognitively demanding as the “complex” tasks, which typically involves the operation of a concurrent secondary task that places a cognitive load on participants. Simple span tasks tap the storage capacity of WM without any additional processing requirements that are characteristic of the complex span tasks, which will be discussed in the following section.

Immediate Memory Span. This is the traditional task used to measure a person’s WM capacity. Digits, letters or words are presented in a list and the participant is required to report the items in sequential order. The size of the list increases until the participant is unable to recall all the items accurately or fails some other predetermined criterion. The various scoring methods will be discussed later. Cavanagh (1972) reported that the average immediate memory span for different items was 7.7 for digits, 6.4 for letters, 5.5 for words, and 3.4 for nonsense syllables. Forward digit span is, on the average, about 2 items higher than backward digit span (Lezak, 1995).

Word span does not appear to correlate highly with comprehension, as measured by the verbal Scholastic Aptitude Test (VSAT). Daneman and Carpenter (1980) reported a non-significant correlation of +.35. This poor relationship led researchers to develop more complex measures of memory spans (see complex spans below). However, more recent data by Engle, Nations and Cantor (1990) revealed higher correlations between simple word spans and VSAT, when the word frequency of the items in the task was controlled for. They found a correlation of +.63 between low frequency word spans and VSAT and a correlation of +.45 between high frequency word spans and VSAT. The implications of word frequency influences on memory span performance will be discussed in the section on long-term memory (LTM) influences.

La Pointe and Engle (1990) manipulated word length and found that immediate memory span for both short and long words correlated with VSAT with coefficients of +.37 and +.34 respectively. The magnitude of these correlations are comparable to the correlation between simple word span and VSAT obtained in the Daneman and Carpenter (1980) study, which did not manipulate word length.

Matching Span. The matching span task differs from immediate memory span tasks in that no overt reporting of the memory list is required. This makes the matching span task critical in determining receptive from expressive deficits for serial recall (Allport, 1984). Participants who only suffer from expressive deficits may perform poorly in immediate spans because of the inability to report the items, but would be able to perform normally on the matching span task. The task involves presenting a list of items (the memory set), followed by a target list, after which participants are required to respond “same” if the two lists are identical, or “different” if they are not. Typically, the lists are made different by reversing the order of two adjacent items (Allport, 1984). Because of the lack of overt reporting, matching span is usually longer than immediate memory span, presumably because overt reporting somehow interferes with WM traces in the latter task, resulting in a reduced span.

Missing Scan. Klapp, Marshburn, and Lester (1983) used this procedure to demonstrate that the capacity limit of immediate memory span is not a good measure of the limits of WM. Participants were presented with a list of 8 of the 9 non-zero digits and were required to report which digit was missing. Presumably, participants had to compare the target list with an activated list of the 9 digits from 1 to 9 in WM to determine the missing number. Thus, the task taps the same resources as a simple digit span.

However, performance in the missing scan is not affected by rhythmic patterning (i.e., temporal grouping in which items are presented in groups of 3) or articulatory suppression. These two factors have been shown to strongly influence immediate memory span (Hitch, Burgess, Towse, & Culpin, 1996; Baddeley, Thomson, & Buchanan, 1975). Klapp et al. (1983) argued that the missing scan results suggest a WM component distinct from the component measured by ordered recall tasks such as immediate span. A major criticism of the procedure is that it has not been tested with letters and words. The use of a closed set of items (i.e., digits) might circumvent the use of WM resources since participants are always comparing the same memory set (the digits 1-9) with the target list. A procedure that varies the memory set might produce very different results.

Sternberg's Short-term Memory (STM) Scan. Although not strictly a measure of WM capacity, Sternberg's (1967) scanning task is a potentially useful procedure to determine the influence of item properties on the search process in WM. Previous research indicated that comparison rates are fastest for digits at 33 ms per item; and slowest for nonsense syllables at 73 ms, with letters, colours, words, geometric forms etc. in between (Cavanagh, 1972). One possible explanation for the variable comparison times is that the search rate depends on the amount of information encoded in the WM trace for each item. More complex items such as random forms and geometric shapes may be encoded and represented with more features than items such as digits. This would be consistent with the finding that multiple talker lists result in smaller memory spans than single talker lists (Saldana & Svec, 1995), because voice variation would result in the encoding of additional features. The Saldana and Svec findings, however, were limited to lists of letters and the extent to which it can be generalised to words, digits and other items would have to be investigated.

Complex Span Tasks

These tasks usually involve two concurrent processes: (1) a primary or criterion task which is similar to a simple span task in which a list of items is to be remembered, and (2) a concurrent secondary task which usually involves some complex manipulations or reasoning. The goal of these procedures is to measure the residual capacity of WM in performing the criterion task while putting the subject under a cognitive load with the concurrent task.

Reading/Listening/Speaking/Operations Span. Daneman and Carpenter (1980) developed the reading span task to obtain a WM measure that is more predictive of language comprehension. The task requires participants to read a set of sentences while remembering the last word of each sentence. After the end of the last sentence of the set, participants are required to perform a serial ordered recall of the last words. To ensure that participants are processing the sentences, they are either (1) required to read them aloud, (2) verify the truth of the sentence, or (3) verify the sensibility of the sentence. Reading span measures correlated .59 with VSAT and up to .90 with performance on fact and pronoun reference questions that tested comprehension of passages (Daneman & Carpenter, 1980).

The listening span test is similar, except that the sentences are presented auditorily. Similar correlations were obtained with measures on reading and listening comprehension of the passages. On reading comprehension, correlations with reading span measures ranged from +.74 to +.86, and from +.67 to +.72 with listening span measures. On listening comprehension, correlations with reading span measures ranged from +.42 to +.78, and from +.47 to +.85 with listening span measures. The reading and listening span measures are highly correlated in the region of +.80 and upwards (Daneman & Carpenter, 1980).

Another variant of this task is the speaking span (Daneman & Green, 1986), in which participants are given a list of words to remember, after which they are required to generate one sentence for each of the words in the correct serial order. Speaking span correlated +.57 with reading span.

Turner and Engle (1989) substituted mathematical operations for sentences as their secondary task to see if the effects of the concurrent task were due to linguistic processing. Operations span also predicted reading comprehension scores, producing correlations with quantitative SAT scores ranging between +.24 and +.33. Although simple digit span did not correlate with comprehension measures, it did correlate with the sentence and operation spans (ranging from +.18 to +.35; the complex spans inter-correlated with each other in the range of +.38 to +.58). Turner and Engle concluded that the nature of the secondary task is unimportant as long as it involved processing or reasoning of symbolic material. However, it should be pointed out that linguistic processing may also play a part in mathematical operations as verbal coding may be utilised (cf. Richardson, 1996).

Daneman and Merikle (1996) conducted a meta-analysis of studies using these complex spans and observed that the average correlational magnitude for comprehension ability was +.41 with sentence tasks and +.30 with operations tasks. In contrast, the correlations for simple tasks involving only the storage component were +.28 for verbal material and +.14 for digits. Thus, complex spans that require participants to engage in *both* processing *and* storage operations appear to be better predictors of comprehension than simple spans involving *only* storage operations.

Embedded Span. This paradigm was developed to determine if two successive lists of items interfered with the processing or storage of the other. Klapp et al. (1983) used this procedure to test if span memory and reasoning processes shared the same WM resources. Participants were given a primary task of memorising a list of letters, which was followed by an embedded task of memorising a smaller list of digits. They were then required to perform an immediate serial recall of the digits, followed by a delayed serial recall of the letters. It was hypothesised that if the two tasks shared the same WM capacity, there should be interference. The results confirmed this hypothesis, even when a consolidation period for rehearsal was given between the primary and embedded task. However, when the embedded task was a reasoning problem (e.g., $5 > 7$, true or false?) or a search task using Sternberg's STM scan procedure, interference occurred only when no consolidation period was given for rehearsing the primary list. Klapp et al. (1983) interpreted this to mean that only the rehearsal processes interfered with reasoning processes, and that memory retention is independent of reasoning or search processes – provided that a consolidation process occurred before the secondary task. Therefore, retention of items in WM may not be using the same resources as other processes (although one could argue that retention uses the residual capacity of WM, which is not involved in the secondary tasks). This would mean that the full capacity of WM is not reached by the retention of items, as measured by simple span tasks.

Concurrent Span. This is a variant of the embedded span, with the two lists being presented simultaneously instead of consecutively. Only one of the lists is to be recalled, and the cue to determine which list to recall comes after the presentation of both lists. Thus participants must store 2 separate lists in WM. The paradigm allows the experimenter to manipulate the properties of each list to observe their effects on span performance.

Richardson (1984) found that imposing a second serial learning task reduces the phonological similarity effect in immediate serial recall. Learning a list of letters and words at the same time reduced the advantage of phonemically distinct words or letters over phonemically similar ones. This reduced advantage was more prominent when letters were to be recalled than when words were to be recalled. Richardson suggests that this result indicates a disruption of the efficiency of phonological coding by a concurrent load. However, it is unclear if a floor effect is confounding the results. Specifically, a concurrent memory load may compete for the same storage resources in the WM system. In this case, overall performance on both tasks may be impaired such that any advantage of phonological distinctiveness will be masked. Nevertheless, the concurrent span paradigm is

potentially capable of revealing whether different aspects of WM are being utilised to process and store lists of differing items.

Component Analysis

A summary of the different WM tasks that I have discussed is provided in Table 1. Having described the nature of these tasks, some important questions can now be raised. What are the functional similarities among the various tasks, and what are the differences? To what extent can we infer the nature of WM processes and components from these tasks? The demand characteristics of most WM tasks can be divided into 3 broad categories: (1) encoding, (2) processing and, (3) output. Let us examine each in turn.

Table 1
Summary of WM Task Procedures

Simple Spans			
<i>Name</i>	<i>Task</i>	<i>Compare</i>	<i>Response</i>
Immediate Memory Span	I_1, I_2, \dots, I_n		I_1, I_2, \dots, I_n I_n, I_{n-1}, \dots, I_1
Matching Span	I_1, I_2, \dots, I_n	I_1, I_2, \dots, I_n I_2, I_1, \dots, I_n	Yes No
Missing Scan	$I_1, I_2, \dots, I_i, \dots, I_n$	I_1, I_2, \dots, I_n	I_i
STM Scan	$I_1, I_2, \dots, I_i, \dots, I_n$	I_i X	Yes No
Complex Spans			
<i>Name</i>	<i>Task</i>	<i>Compare</i>	<i>Response</i>
Reading/Listening Span	$S_1 + I_1, S_2 + I_2, \dots, S_n + I_n$		I_1, I_2, \dots, I_n
Operations Span	$M_1 + I_1, M_2 + I_2, \dots, M_n + I_n$		I_1, I_2, \dots, I_n
Speaking Span	I_1, I_2, \dots, I_n		$S_1 + I_1, S_2 + I_2, \dots, S_n + I_n$
Embedded Span	$(I_1, I_2, \dots, I_n) (J_1, J_2, \dots, J_n)$		$(J_1, J_2, \dots, J_n) (I_1, I_2, \dots, I_n)$
Concurrent Span	I_1, I_2, \dots, I_n J_1, J_2, \dots, J_n		I_1, I_2, \dots, I_n
<i>Key: I, J = items; S = sentence; M = math operation</i>			

Encoding. Factors that affect encoding include (1) stimulus clarity, and (2) the number of stimulus attributes or amount of information per item.

Sternberg (1967) showed that stimulus clarity affected reaction time (RT) in his scanning STM task, such that degraded targets increased participants' RTs. This did not interact with the size of the memory set, suggesting that encoding and search processes are independent. Most of the other WM tasks do not vary stimulus clarity directly but there are methods used to disrupt encoding. For example, articulatory suppression (Baddeley et al., 1975), in which participants repeat an irrelevant word such as "the" during presentation and recall, is assumed to disrupt the encoding of the stimulus items into a phonological code, resulting in reduced spans. However, it is unclear if the locus of the articulatory suppression effect is due to a disruption of encoding or a disruption of rehearsal, because the latter is also affected by the irrelevant articulation required to perform this task.

The amount of information present in the stimulus appears to be more important than the actual memory set size. Saldana and Svec (1995) demonstrated that multiple talker lists resulted in shorter immediate memory spans than single talker lists, suggesting that information about the variability of the memory set is also encoded, rather than just the number of items. However, it appears that only salient information affects memory span, as multiple amplitude lists were no different from single amplitude lists. Indexical aspects of speech, such as voices, contain salient information in everyday language use, and are probably encoded holistically with the symbolic information of verbal material. This finding is consistent with research demonstrating that unattended speech, but not unattended noise, disrupts immediate memory span (Salame & Baddeley, 1987; 1989). Further research on the effects of the number of stimulus dimensions on memory span performance is needed in order to gain a better understanding of the factors that affect WM spans.

Processing and Retrieval. Factors affecting the processing and manipulation of material include (1) temporal order, (2) search and comparison, and (3) cognitive load. These factors are dependent on the nature of the tasks.

Temporal order refers to the sequence in which a list is processed and retrieved. In general, forward recall (in which participants are required to report the items in the order in which it was presented) has a longer span than backward recall. This is assumed to reflect the additional manipulation requirements of backward span. One possibility is that participants initially retrieve the list in a forward order and then read it off backwards. This additional requirement potentially uses more WM resources, resulting in a lower span. The immediate memory span task and most of the complex span tasks require ordered recall, with the latter exclusively in the forward direction.

For comparison tasks, participants are required to compare a target list or item with a presented list. It is assumed that a search of the WM store for the traces of the presented list occurs. These traces are then compared with the traces of the target items. Because these tasks do not require participants to overtly report a presented list, factors that affect processing, such as set size, are free from interference or disruption due to overt reporting. For example, memory spans as measured by a matching span task tend to be longer than the traditional digit span task. Comparison tasks allow the examination of search rates in WM by looking at reaction times as a function of set size. Capacity limitations can also be examined by looking at performance deterioration as the set size increases in matching span and missing scan tasks.

The complex span tasks, by definition, are the paradigms that impose an additional cognitive load by introducing a secondary task. This additional task presumably taxes the WM system if it requires the same resources as the primary task. Most of the primary tasks (which are effectively immediate memory span tasks) require ordered serial recall, although it is technically feasible to conduct matching or comparison tasks. For example, in a reading span task, one could present a list of words after the sentence set and ask participants if the list matches the last words from each sentence.

The reading and operations span measures were developed to predict language comprehension abilities rather than to distinguish among WM processes. The rationale for these measures was that people with better linguistic abilities would use less WM resources to process the secondary task, leaving more for the storage of items in the primary task. This would then be reflected in a higher residual WM span. Conversely, people with inefficient linguistic processing skills may devote more WM resources to process the secondary task, and thereby reducing their capacity for storing the primary task items. The embedded and concurrent span paradigms were developed to directly test whether WM processes involved in memorising a set of items interfered with another process that may or may not tap the same resources.

Output. The output required for the various WM tasks can be categorised as either (1) full report or (2) discrimination/identification. In the full report procedure, the entire list of items must be repeated. In the discrimination/identification procedure, either a binary response is made (i.e., yes/no or same/different) or a single item from the memory set is reported.

The full report procedure is used in the immediate span tasks and all of the complex span tasks. These tasks usually require ordered serial recall, although free recall may sometimes be used instead. The tasks involving comparisons and search, namely, the matching span, missing scan, and search paradigm, do not require an overt report of all the items in the memory set. Instead, these tasks use the discrimination/identification procedures which require only receptive ability and are presumably less susceptible to expressive impairment. Full report procedures, on the other hand, assume that *both* receptive and expressive abilities are intact.

Scoring Procedures

There are several ways to score performance in the various memory span tasks, Researchers may use one or more of these methods. Sometimes, researchers will report only one scoring method after stating that there were no differences among the different methods used.

1. Strict span score (Daneman & Carpenter, 1980) is the number of trials that are recalled perfectly on 2 out of 3 trials of a given set size or list length. If a subject obtained a perfect score on only 1 trial at the next higher set size, half credit (0.5 points) is given.
2. Absolute span score (La Pointe & Engle, 1990) is calculated by summing the total number of items in each perfectly recalled trial.
3. Total span score (La Pointe & Engle, 1990) is the total number of items recalled correctly, regardless of whether the trial was perfectly recalled or not.
4. Highest span score (Broadbent, 1971) is the largest set size or list length where all trials are perfectly recalled, rather than the size at which recall is 50% or more correct.

It should be pointed out that researchers differ in adhering strictly to the serial order of the items to determine whether a trial is perfect. Some will count words as being correctly recalled regardless of serial order (usually those employing complex span tasks, see Engle (1996)), whereas others will only consider trials in which temporal order is also maintained (which is the case for most simple span tasks). If temporal order is considered, some researchers will also report the number of items recalled in the correct serial position and the number of items in correct runs of 2 consecutive positions, in addition to the number of trials which are totally correct. Table 2 lists examples of the different scoring procedures.

II. Some Experimental Issues and Findings

Memory Span Items

We now turn to a discussion of item effects on memory span. That is, do the nature of the items in the memory set affect measures of memory span? Clearly they do. As discussed earlier, Cavanagh (1972) demonstrated that using digits as the memory set resulted in longer spans than letters or words. In addition, the average search time for each item in WM is inversely related to its immediate memory span. Items with longer spans have faster search rates. Thus, digits have the fastest search rate, whereas words have a slower search rate. Whether matching span times and missing scan times are also influenced by the nature of the items remain to be seen. Research using

the matching span and missing scan paradigms has thus far reported only the list length scores but not search rate.

Table 2

Examples of Scoring Procedures

List Length	Trial	Presented List	Response
2	1	1 2	1 2
	2	3 4	3 4
	3	1 4	1 4
3	1	1 2 3	1 2 3
	2	2 3 4	2 3 4
	3	4 2 1	3 2 1 *
4	1	4 2 1 3	4 2 1 3
	2	1 2 3 4	1 3 2 4 *
	3	3 1 2 4	5 2 1 3 *
Strict Span Score: 3.5 Absolute Span Score: $6 + 6 + 4 = 16$ Total Span Score: $6 + 8 + 6 = 20$ Highest Span Score: 2			
* incorrect items and/or order			

Closed vs. Open Set Items. Closed set items refer to a group of items that form a distinct class whose membership is fixed. That is, no new items can be added to the set. Digits, letters, and function words are examples of closed sets. An open set refers to a group in which new members can be added. An example is the set of nouns. This distinction is potentially important for memory span studies. One of the problems of using closed sets or small vocabularies is that participants can combine partial information for a given item with their knowledge of the constraints within the set to develop guessing strategies (Drewnoski & Murdock, 1980). For example, memory for the [I] sound in a digit span task might lead participants to infer that it was a 6 rather than 5 or 9. Another problem with using stimuli from a closed set is the increasing levels of proactive interference (PI) as items get repeated from trial to trial. Notice that these two factors predict opposite effects. A restricted range for guessing should lead to better span performance, whereas PI should impair performance.

A recent study by Coltheart (1993) showed that immediate memory span for words repeatedly sampled from a small pool was larger than words sampled without replacement from a large pool, provided that the words were phonologically dissimilar. There were no differences in performance when the words were phonologically confusable. This finding suggests that the restricted range facilitated performance rather than contributed to the effects of PI—the latter should have led to lower spans for repeated words relative to novel words. The fact that no difference was found for phonologically similar words lends further support for the restricted range argument, as there would be no guessing advantage of a restricted range if all the words sound similar.

It would be interesting to investigate this effect further with other WM tasks and with different memory set items. Most words used in such experiments do not form a naturally occurring

closed set. Therefore, it may be useful to investigate this effect with words that form a true closed set such as numbers, letters or function words. One can also speculate that if more dimensions are added to a closed set list, it may reduce the advantage of the restricted range. Encoding an increasing number of attributes for each item may effectively increase the amount of information in WM, and as a result, increase the range rather than restrict it. This hypothesis is consistent with the letter span results obtained by Saldana and Svec (1995), which showed an advantage for single talker lists over multiple talker lists. If increasing the amount of information reduces the advantage of a restricted range, it may in turn increase the effects of PI, which could have been previously masked by the restricted range advantage.

It might be possible to examine this hypothesis with a release from PI paradigm (Wickens, Born, & Allen, 1963). When consecutive memory sets contain items from the same semantic category, recall performance drops because items from earlier sets interfere with the recall of items from the current set. However, if the subsequent memory set contains items from a different category, recall performance returns to initial performance levels.

It is assumed that participants are “released” from the effects of PI because the change in category is attended to. This means that any change, addition, or deletion of a stimulus dimension may be sufficient to cause a release from PI. With closed sets or repeated samples, the *addition* of another dimension will increase the range of the set by adding more information and thereby increasing the variance. This may have two consequences: 1) it may reduce the advantage of a restricted range, and 2) it may allow PI effects to set in. However, the *deletion* of a dimension may restrict the range even further and strengthen immunity from PI.

It is predicted that a switch from a list produced by a single-talker to a list produced by multiple talkers, while using a repeated sampling paradigm, would increase PI. This is because one is increasing the amount of information in WM by introducing more variation in the voices, and so restricted range advantages would be reduced. One would predict the opposite effect if a switch were made from a list produced by multiple talkers to a list produced by a single talker, while keeping the list items the same. In this case, the information in WM is reduced, allowing participants to benefit from the restricted range of a closed set.

La Pointe and Engle (1990) also explored the effects of repeated and non-repeated sampling. They found that the word length effect, which refers to the finding that memory span is inversely related to the length of the words (Baddeley et al., 1975), was not abolished by irrelevant articulation if the words were sampled from a large pool without replacement. This result casts doubt on the articulatory rehearsal explanation of the word length effect (Baddeley et al., 1975), which stated that concurrent articulation should abolish the word length effect regardless of repeated or non-repeated sampling. It is unclear why non-repeated sampling should be immune to articulatory suppression. One hypothesis is that novel presentations may encourage the use of more than one type of coding strategy that does not make use of the articulatory loop.

Representation in Working Memory

One of the major issues in WM research concerns the nature of the memory representation or code. In what form are items in WM stored? Although much research has investigated the storage and manipulation of visual images in WM, I will restrict this discussion to evidence related to linguistic material, given the goal of this review.

The Phonological Similarity Effect. Early research provided evidence for a phonological code for STM and a semantic code for LTM. Memory span for a list of phonologically similar words was found to be worse than the memory span for a list of phonologically dissimilar words or for a list of words which are semantically similar (Baddeley, 1966). However, for long-term learning and

retention of words, semantic similarity enhances recall whereas acoustic similarity does not. The observed effect for similar sounding words in short-term recall is called the phonological similarity effect. This was the impetus for Baddeley to propose a phonological loop component that deals with verbal information in his WM model. Items entering this component are converted into a phonological trace. The discriminability of an item, therefore, depends on the extent to which its phonological features differ from the phonological features of other traces.

The Unattended Speech Effect. Further support for a phonological trace for WM comes from research that introduced irrelevant speech during the visual presentation of digits. Recall is equally disrupted by meaningful words, nonsense syllables, spoken digits, and words which contained some of the phonemes of the digits (e.g., *tun*, *woo* instead of *one*, *two*) (Salame & Baddeley, 1982). The overall results indicate that the unattended speech effect is caused by the phonological disruption of the WM trace, and not the semantic content. If semantic content were important, meaningful words and spoken digits should be more disruptive than the other two conditions. It was also shown that only verbal material will disrupt recall, as unattended noise did not have an effect (Salame & Baddeley; 1987, 1989).

The Word Length Effect. Another major finding in the WM literature is the word length effect. That is, memory span is inversely related to the length of the word. The locus of this effect is thought to be the duration of the word rather than the number of syllables. Lower spans are obtained when lists are comprised of words with a longer spoken duration such as *Friday* and *harpoon* than words such as *wicket* and *bishop* (Baddeley et al., 1975). This is consistent with the notion that phonological features, rather than semantic features, are the primary way that information is encoded in WM. Also, participants who use languages with a faster articulation rate tend to have longer digit spans. Digit spans tend to become shorter as one goes from Chinese, to English, to Malay, and to Welsh (Ellis & Hennessey, 1980; Naveh-Benjamin & Ayres, 1986; Hoosain & Salili, 1988; Elliott, 1992). Word length effects have also been demonstrated in both simple and complex span tasks (La Pointe & Engle, 1990). Baddeley (1998) attributes the word-length effect to the rate at which items can be rehearsed by the articulatory loop. The faster this can be done, the less the trace decays in the phonological store. Words with longer durations will reduce the number of traces that can be kept active, resulting in lower spans.

The explanation may turn out to be more complicated because lexical complexity and duration seem to have an influence on recall performance (Cowan, Wood, Nugent, & Treisman, 1997). Words which are more complex, as measured by the number of elements, such as disyllabic words, turn out to have an advantage over less complex monosyllabic words. Cowan et al. (1997) suggest that items defined by more information are more resistant to interference than less complex stimuli. Although information is lost through decay or interference, sufficient information is retained by the more complex items to cue the correct response. As in the section on closed vs. open set items, it appears that the amount of information attached to each item may be a critical factor for WM processes. Variables such as multiple talkers, multiple speaking rates, and multi-modal inputs may all have important influences on WM performance.

Another recent finding is that the word length effect appears to emerge only after extended trials in an immediate span task with repeated sampling. That is, there is no difference in performance between long and short words on initial trials (Nairne, Neath, & Serra, 1997). This suggests that the locus of the effect may involve proactive interference factors, and not simply a reflection of the duration of the WM trace.

Articulatory Suppression. The word length and phonological similarity effects can be abolished by articulatory suppression under certain conditions. Word length effects are generally negated by articulatory suppression (Baddeley et al., 1975). However, La Pointe and Engle (1990) found that this does not apply to words sampled without replacement. The phonological similarity

effect is abolished only if the list presentation is done visually. This suggests that the articulatory loop is used to recode the items in the visual list to a phonological code. When the list is presented auditorily, articulatory suppression has no effect because the stimuli directly access the phonological store and do not need to be recoded (Baddeley, Logie, Nimmo-Smith, & Brereton, 1985).

However, the situation is not that simple. Bavelier and Potter (1992) found evidence for a phonological code that is impervious to articulatory suppression. When lists of words are visually presented at a very rapid rate of 100-117 ms per item, an effect known as repetition blindness causes the second occurrence of a word to be missed when the repeated word is presented in close proximity to the original presentation (Kanwisher, 1987). Orthographically similar words are usually affected (Kanwisher & Potter, 1990), but homophones are also susceptible to this (Bavelier and Potter, 1992). Articulatory suppression does not remove this effect, suggesting that recoding the visual stimulus into an auditory representation may involve some kind of very early phonological code that registers the item in WM. This code differs from the one used for recalling items from WM because it is not susceptible to articulatory suppression. More investigation into the existence of this code and the extent to which it is relevant to WM is needed.

Long-term Memory Influences

Lexical Effects. We are now heading into the realm of LTM influences on WM. Does the organisation and structural properties of words in LTM have an effect on WM processes? Engle, Nations, and Cantor (1990) demonstrated that word frequency influences memory span performance in both simple and complex span tasks. Memory spans were longer for lists comprised of high frequency words than lists comprised of low frequency words. However, the word frequency advantage was smaller in complex span tasks. A word frequency effect implicates LTM influences on WM because word frequency information can only be represented within LTM as a result of experience. Thus, immediate memory span measures for word lists may be affected by information stored in LTM.

Are there any items that can be used as a “pure” measure of WM that will not be contaminated by LTM knowledge? Some might argue for the digit span because the 10 digits are a closed set of items that are very familiar and very frequent. If this is true, one might argue for a function word span because these items are also a closed set that is very familiar and very frequent. However, performance on the digit span may be superior to performance on the function word span simply because people are more practiced at memorising a string of numbers in everyday life.

Other lexical properties of words influence recall in memory span tasks. Drewnowski and Murdock (1980) observed that intrusion errors tend to share auditory features with the omitted words. More detailed analyses revealed that these features tend to match the syllabic stress pattern and the stress placed on the vowel of the omitted word. Drewnowski and Murdock suggest that the vowel-to-vowel transitions might be a key feature of the auditory traces in STM. Evidence also suggests that phonotactic transition probabilities (Auer & Luce, submitted) and the neighbourhood structure of the words in the lexicon (Luce, Pisoni, & Goldinger, 1990) influence the speed and accuracy that words are accessed from LTM. Because WM is influenced by LTM, the effects that these properties of words in the lexicon have on word span tasks should be investigated.

A cautionary note is perhaps in order at this point. Lexical properties affect the ease of accessing the word from LTM. However, once the word is accessed and a representation stored in WM, it may be the case that LTM influences should no longer affect processing of the WM traces. Why should the neighbourhood structure of a word in one system (LTM) continue to have an effect when the word has been, in some sense, “transferred” to another system (WM)? The answer may be that the two systems are more intimately related than we realise. If lexical properties represented in

LTM continue to exert an influence on WM, models that posit two functionally separate systems may no longer be viable.

Roles of Other Codes. There is also evidence for the use of codes other than phonological ones for representing items in WM. Wetherick (1975) explored the effect of using items from single versus multiple semantic categories in immediate memory spans. The results showed that recall performance was negatively related to the number of categories from which the items were selected. This result parallels the finding that multiple talker lists were detrimental to recall (Saldana & Svec, 1995). An effect of semantic categories suggests that participants were using pre-existing semantic relationships among words in LTM for recall. Wetherick postulated that if semantic information was coded directly rather than in a phonological form, there would be a clear advantage for single category lists because items from the same semantic category are structurally closer than items from different categories. On the other hand, the explanation offered by Saldana and Svec for the multiple talker effect is also a plausible alternative. More categories may imply more information to be encoded in WM, and this translates directly to the use of more WM resources per individual item, resulting in a smaller overall WM span.

Further support for a semantic component to WM comes from a series of neuropsychological case studies (Martin, 1993; Martin & Breedin, 1992; Martin & Romani, 1994; Martin, Shelton & Yaffee, 1994). These reports describe patients who have a severe deficit in immediate memory span, but have normal comprehension of speech and language. They are, however, unable to perform other tasks that require the maintenance of verbatim phonological material. This apparent dissociation suggests that the retention of items in the phonological store may involve a component of WM that is functionally separable from those involved in language and speech comprehension. For example, Martin, Shelton, and Yaffee (1994) proposed separate capacities for phonological and semantic retention after describing two patients who exhibited reversed patterns of deficits. The patient with the phonological retention deficit was impaired in sentence repetition but not sentence comprehension. However, the patient with the semantic retention deficit was impaired in sentence comprehension but not sentence repetition.

III. General Theoretical Issues

Is Working Memory Distinct from Long-term Memory?

There are three positions on this issue (Richardson, 1996). The original model of WM by Baddeley and Hitch (1974) and subsequent revisions take the position that WM is structurally separate from LTM. The WM system itself comprises distinct components which are themselves structurally separate from one another: (1) the phonological loop, (2) the visuospatial sketchpad, and (3) the central executive. Neuroimaging evidence suggests that there are portions of the brain that appear to be functional equivalents of these components (D'Esposito, Detre, Alsop, Shin, Atlas, & Grossman, 1995; Jonides, Smith, Koeppe, Awh, Minoshima, & Mintun, 1993; Kimberg & Farah, 1993). However, the neuroimaging studies do not address the issue of the separability of WM from LTM.

A second position argues that WM is merely the area of LTM that is currently active. Thus, it is not a structurally separate component of the human cognitive system. This account posits WM as the temporary raising of the activation levels of LTM structures. Anderson, Reder and Lebiere (1996) and Engle (1996) take this position.

A third position, advanced by Hasher and Zacks (1988), argues that the contents of WM are based on the activation of LTM representations. However, WM is still considered a distinct structural component of the information processing system. Interpretative processes within LTM activate the

nodes and items relevant to the task at hand and these items are reflected in the WM component. This account is essentially a bridge between the other two.

Constraints on Working Memory

All three accounts agree that there are limited resources available for WM, but their different theoretical approaches conceptualise these capacity limitations in very different ways (cf. Richardson, 1996). For Baddeley's model, these limitations are due to the allocation of attentional resources by control mechanisms. This can be seen in performance during cognitively demanding tasks such as preload with concurrent processing. In this model, the word length effect is due to the rate of articulatory rehearsal. Articulatory rehearsal maintains information in the passive phonological store. Immediate memory span is believed to measure the storage capacity of this component.

For the other two approaches, which posit WM as the set of activated links in LTM, capacity limitations are due to the automatic spreading and decay of activation levels within LTM structures. These processes can be observed in the "fan" effects that are obtained for tasks that involve storing and retrieving facts. For these accounts, the current activation levels control the rate of processing. Those items that are more active will be processed faster than those items that are less active. Immediate memory span measures the sustained capacity of WM rather than the amount of information that is momentarily active. In this theory, the amount of information that is activated could be quite large. If the set of items exceed the capacity of WM, only those items with the highest activation levels will be reported.

Recently, Richardson (1996) pointed out that WM is likely to be constrained by both controlled attention and automatic activation processes. Which constraint is more important remains an empirical issue. The importance of one constraint over another may be task dependent. However, for all accounts, the capacity of WM is not posited as a discrete quantity but an emergent property of the underlying processes. The *effective* WM capacity could be a result of the efficiency of the underlying processes and strategies that people employ in experimental tasks.

Inhibition and Interference

Inhibition refers to the processes and mechanisms that serve to prevent irrelevant information from gaining access to WM, thereby reducing the amount of available resources. Inhibitory mechanisms are a crucial feature of the Hasher and Zacks (1988) model of WM. They discovered that memory deficiencies found in older adults are not a result of reduced storage capacity but are due to a reduction in the efficiency of their inhibitory mechanisms. Hamm and Hasher (1992) found that older people maintain the different interpretations of ambiguous passages, even when the correct interpretation has already been implied. The work of Gernsbacher also implicates the use of inhibitory mechanisms (she uses the term *suppression*) in general cognitive processing. For example, Gernsbacher and Faust (1991) found that high comprehension participants dropped irrelevant meanings faster than low comprehension participants did. This, however, should be contrasted with other research by Just and Carpenter (1992), who found that high WM participants were able to retain irrelevant meanings of ambiguous phrases for a longer period of time than low WM participants. Engle (1996) pointed out that the crux of this issue is whether individual differences in WM capacity reflect inhibitory or activation processes. Gernsbacher and Faust (1995) argue that suppression is a result of active reduction in activation rather than passive decay or compensatory inhibition. This contrasts with the Just and Carpenter (1992) suggestion that lateral inhibition occurs when increased activation in certain nodes leads to the simultaneous decrease in activation of other nodes. Gernsbacher and Faust also argue that suppression varies with the task demands and the experimental context. This indicates that it is not an automatic and obligatory process, but may well be under strategic control.

It is also worth noting that the term *inhibition*, as used here, refers to active, directed, and effortful suppression (Bjork, 1989). Another use of the word inhibition refers to the effect of selecting one item over another because the activation level of one item is higher than the other. Bjork refers to this process as *blocking* rather than active inhibition – the item with a higher activation blocks the one with the lower activation, rather than inhibiting it. It remains to be seen whether both kinds of processes play a part in WM.

Inhibition can be contrasted with interference. Interference refers to properties between items that affect processing in WM. The phonological similarity effect is one example. Immediate memory span for items that are phonologically similar is much lower than for items that are dissimilar (Baddeley & Hitch, 1974). Semantic similarity among items also causes a reduction in immediate memory span relative to unrelated items, but not as profoundly as phonologically similar items. These results have been taken to indicate that the code of WM is phonological in nature, at least for the verbal component. However, if one takes the view that WM is the temporarily active portion of LTM and is not a distinct component of the cognitive system, it is unclear how these results would be accommodated. It is well known from priming studies that semantically related items could be considered to be stored “closer” together, so that activation spreads to these nodes faster than to unrelated nodes. Similarly, one could construe a distance metric for the phonological dimension. It is, therefore, unclear why properties of the items that facilitate activation in LTM should cause interference in WM. One possibility is that the locus of the effect is in the output mechanisms. Control processes that align the items for serial output, such as sub-vocal rehearsal, may be affected by certain item properties. Indeed, Klapp et al. (1983) argued that temporal grouping and articulatory suppression only affect the maintenance of serial order information. Tasks which do not require serial output, such as the missing scan task used in the Klapp et al. study, are unaffected by such factors.

The disparity between the influence of item properties on LTM and WM processes seem to indicate that at least some component of WM must be distinct from LTM. A study by Conway and Engle (1994) showed that although set size affected the time to scan for a target item (replicating the results of Sternberg’s STM scanning experiments), it did not affect the amount of time required to retrieve the information from LTM. Although Engle takes the position that WM is just the active portion of LTM, it may be illuminating to see if retrieval time would be affected by phonological and semantic similarity among the items. According to past findings, item similarity should facilitate retrieval time from LTM but interfere with search in WM.

General vs. Multiple Working Memories

Is WM a single unitary component with a general-purpose pool of resources or is it a complex system with multiple domain-specific resource pools? If WM is a unitary component, resources must be flexibly allocated to the tasks at hand. However, if WM is a multi-component system, then the separate resources are independent of one another and cannot be reallocated to tasks outside of their specific domain.

Proponents of a general unitary WM system (e.g., Daneman & Carpenter, 1980; Just & Carpenter, 1992; Turner & Engle, 1989) point to the success of complex span tasks in predicting reading comprehension abilities. The conclusions of these studies generally appeal to the following rationale. The secondary processing tasks include a range of specific skills—mathematical ability, sentence processing etc.—which are not specific to reading. The primary storage task measures the residual capacity of the WM system after most of it has been allocated to the secondary task. As the predictive power of the measure does not change with the nature of the secondary processing task, it follows that all types of secondary task are tapping into the same general resource capacity, and whatever is leftover is used for storage. Thus, individuals with better general cognitive processing

skills require less general resources for the secondary task, and have a greater capacity for the primary storage task.

Proponents of multiple domain-specific resources generally appeal to neuropsychological evidence showing functional dissociations and selective impairments of specific cognitive abilities. Separate components for semantic and phonological modules (Martin, Shelton, & Yaffee, 1994), arithmetical ability (Butterworth, Cipolotti, & Warrington, 1996), and visuo-spatial modules (cf. Baddeley, 1998) have been proposed. Richardson (1996) pointed out that the proponents of a unitary system are largely conceptualising WM at the level of Baddeley's central executive module, where the focus is on attentional systems that control processing of high level cognitive functions. Multiple component theorists are largely conceptualising the domain-specific resources at the level of Baddeley's subsidiary systems. The two approaches may not be entirely incompatible if there exists a component of WM that is responsible for executive functioning, but not short-term recall as measured by simple span tasks, and, conversely, a component of WM responsible for short-term recall but not executive functioning. Brain imaging studies have suggested that the frontal lobes may be the centre for executive processes, while other areas in the cortex appear to be responsible for the processing of verbal and spatial information. Future developments in this field may shed more light on the issue of unitary vs. domain-specific components in the WM system.

Conclusions and Future Directions

Several issues emerge from this selective review of WM research in experimental psychology. First, it appears that the amount of information within each item in a memory set influences memory span performance. It will be critical to uncover precisely which features of the stimulus are encoded in the WM trace, which aspects of the WM tasks these features will affect, and whether the saliency of these features depends on the level of processing required. For example, voice information affects immediate memory span procedures, but will it have the same effect on complex span tasks or those requiring scanning and identification of a target?

Second, inhibitory processes and interference effects must be seriously considered in accounts of WM. The effects of closed and open sets, repeated sampling and sampling without replacement may be contingent upon a complex interaction of information load, restricted range, and interference factors. WM performance may also be contingent upon individual differences in the efficiency of inhibitory mechanisms (Conway & Engle, 1994; Engle, 1996).

Third, the influence of LTM on WM deserves further investigation. No set of items used to measure WM span can truly be free from LTM influence. Even a memory span task using nonsense words will be affected by knowledge of the distribution of phonological forms in the language. Hence, it is important to investigate the extent to which LTM interacts with WM.

Finally, investigation of the role that WM plays in language processing must be conducted. It is clear that WM has a limited capacity; so for extended discourse, it is implausible that a person will be able to store verbatim the entire course of a language event. If language processing is dependent on this limited capacity, and if an increase in information load fills up this capacity, then the system can only handle this in one of two ways. One possibility is that the system could have evolved to favour the rapid extraction and inference of higher level linguistic units, while rapidly dropping the traces of lower level units once the higher units have been extracted. This method of operation serves to maintain a sustained WM capacity for incoming information and prevents overloading the system with too much information. Thus, the phonological components of a sentence may be rapidly dropped from WM once the words have been accessed, and so on, with only the semantic information of higher linguistic units kept in WM to await integration with incoming information. The other possibility is that linguistic information directly activates LTM representations. The

LTM representations that are relevant to the current state of processing will then be active enough to “rise” to the conscious level of WM. It remains to be seen which account, or perhaps certain elements from both, will have greater explanatory power regarding the role of WM in language processing.

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