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<p>This article describes a research program addressing several issues about the role of individual differences in working memory and reading comprehension. The studies show a strong positive relationship between measures of working memory capacity and higher level measures of comprehension. More importantly, this relationship does not require that the working memory measure be a form of the comprehension measure. At least one variable known to be important in simple word span, word length, is also important to the complex working memory measures used here and elsewhere and this has important implications for theories about the link between working memory and higher level tasks, at least those of a verbal nature.</p>							
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This article describes a research program addressing several issues about the role of individual differences in working memory and reading comprehension. The studies show a strong positive relationship between measures of working memory capacity and higher level measures of comprehension. More importantly, this relationship does not require that the working memory measure be a form of the comprehension measure. At least one variable known to be important in simple word span, word length, is also important to the complex working memory measures used here and elsewhere and this has important implications for theories about the link between working memory and higher level tasks, at least those of a verbal nature.



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WORKING MEMORY CAPACITY: AN INDIVIDUAL DIFFERENCES APPROACH

Many higher level cognitive tasks make demands on a limited capacity system and this function has generally been attributed to a short-term memory (STM) structure. However, Baddeley and Hitch (1974) and Baddeley (1986) have pointed out that attempts to relate traditional STM measures with measures of higher level functioning, such as reasoning, learning and reading comprehension have not been successful. They proposed that a model of working memory (WM) must include both storage and processing components to be complete. They proposed three structural components: (1) a central executive, (2) an articulatory loop, and (3) a visuo-spatial sketch pad. The articulatory loop and the visuo-spatial sketch pad are considered maintenance systems controlled by the central executive. They argued that the central executive is a flexible controller with limited capacity, and that part of this limited capacity is used for processing incoming information with the remainder used for storage of the products of that processing. When greater effort is required to process information there is less capacity remaining to store the products of that processing. Thus, the central executive is responsible for dividing up the available resources between the dual functions: the processing of information and the storage of information within a limited capacity system. Baddeley and his colleagues have presented evidence for the existence of their proposed WM slave components, the articulatory rehearsal loop (Baddeley & Hitch, 1974; Baddeley, 1979; Salame & Baddeley, 1982), and the visuo-spatial sketch pad (Baddeley & Lieberman, 1980).

Other models of WM have been developed (e.g., Klapp, Marshburn & Lester, 1983; Brainerd & Kingma, 1984, 1985; Case, 1978; Anderson, 1983; Monsell, 1984; Schneider & Detweiler, 1987; and Fletcher & Bloom, 1988), but virtually every conceptualization of WM assumes that there is a limitation in the amount of information that can be kept active at any given time. Further, it is generally assumed that this limitation affects consequent processing. That is, higher level processing is limited to some extent by the limitations of WM. Beyond these generalizations about the WM, however, there is great disagreement about the nature of the WM capacity limitation. The work performed under this grant was designed to speak to this issue through an individual differences approach.

The primary question was whether WM capacity for a given individual is a function of that person's skill in the concurrent task being performed while measuring the WM storage capacity. Or, is WM capacity a

stable individual difference, independent of the task being performed at the time? Daneman and Carpenter (1980, 1983) hypothesized that WM is used to represent the strategies and skills used in reading and any remaining WM capacity is used to store the products of reading comprehension like facts and propositions. They suggested that while this information was being processed and the products of this processing stored, the two functions, processing and storage, must compete for the limited capacity in WM. Further, they hypothesized that individual differences in reading comprehension could be due to readers having "more" or "less" efficient processing skills. For example, a reader with more efficient reading strategies and processes (i.e., a good reading comprehender), would have more capacity available for storage than a reader with less efficient processes. Consequently, good readers have "more" WM capacity for products simply because they have more efficient reading skills, i.e., are good readers. Accordingly, individual reading span measures indexing WM capacity (i.e., the number of products) should be tied to a specific processing task, i.e., reading. To restate this idea, good readers would have more available WM capacity during reading because of their efficient reading skills and processes, but that this greater WM capacity is peculiar to reading tasks and the good reader might have less WM available when performing a non-reading task. I will call this theory the **Task Specific Theory**.

Daneman and Carpenter (1980) developed a measure of WM capacity which required both processing and storage in WM. The task was really two tasks performed concurrently and/or sequentially. The critical task, a memory-span test, was embedded in a secondary reading task in which subjects read series of unrelated sentences. Daneman and Carpenter assumed the reading task differentially limited the storage capacity of WM for the concurrent primary memory task which was recalling the last word of each sentence in the series. The number of last words recalled against the background of this reading task was defined as the subject's Reading Span. The measure was assumed to reflect individual WM storage capacity, presumably specific to other reading situations. Daneman and Carpenter (1980) found reading span measures correlated highly with three different reading comprehension measures: answering fact questions ($r=.72$), pronoun reference questions ($r=.90$), and the Verbal Scholastic Aptitude Test (Exp. 1, $r=.59$, Exp. 2, $r=.49$). However, a simple word span test given to the same subjects did not significantly correlate with any of the reading comprehension measures. Further, in two later studies, Daneman and Carpenter (1983) found significant correlations of .46

and .58 between reading span and Verbal SAT. A similar correlation between WM span and the Nelson-Denny standardized test of reading comprehension ($r=.53$) was found by Masson and Miller (1983).

Daneman and Green (1986) found that the WM reading span was also strongly correlated with the ability to learn new word meanings in a context wherein there are sufficient cues for inferring the precise intended meaning ($r=.69$).

Daneman and Green (1986) and Daneman and Carpenter (1980, 1983) have argued that the reading span measure is an index of the capacity in working memory that is NOT allocated to processing (i.e., reading and comprehending) the individual sentences, and that since good reading comprehenders have better or more efficient processing strategies than poor reading comprehenders, more capacity would remain for "storage" of to-be-remembered information. However, Daneman and Green (1986) had also found that the correlation between reading span and the ability to learn new word meanings was still highly significant when vocabulary knowledge effects were statistically removed ($r=.53$). This suggests that subjects with large spans can more easily learn new words than those with small spans even when contextual cues are absent. That is, there may be something basically "different" between large and small span subjects, other than differential reading strategies, that leads to remembering larger and smaller numbers of contextual cues in a WM capacity.

Another possible explanation of Daneman and Carpenter's findings may be that people are good readers because they have a large WM capacity independent of the task being performed. According to this view, a measure of WM would successfully transcend task dependency in its prediction of higher level cognitive functioning. That is, the memory span test could be embedded in a secondary processing task that is unrelated to any particular skills measure and still predict success in the higher level task. This view sees the individual differences in working memory as reflecting a relatively stable characteristic of the subject. I will call this the **Trait Theory**. Somewhat independent of the issue of whether WM capacity transcends task or not is whether there is a unitary working memory or some number of domain-specific working memories (Schneider & Detweiler, 1987). The view guiding our research is that the Trait Theory is closer to the truth than the Task Specific Theory and that the number of elements responsible for the important individual differences in working memory is small, possibly one or two.

Studies performed in our lab support the notion that WM capacity is not dependent on the task being performed, at least to the extent argued by Daneman & Carpenter. We found that if a memory span task is embedded in a processing task other than reading, the span task still correlated with measures of reading comprehension (Turner & Engle, 1986). Three span measures of WM were given to 37 subjects. First, a memory span task was given that replicated Daneman and Carpenter's (1980) measure of WM capacity. Subjects read a series of sentences and were asked to recall the last word in each sentence (i.e., sentence-word span test, SW). We also used a memory span task in which subjects read a series of sentences with a to-be-remembered digit following each one, (i.e., sentence-digit span test, SD). Reading span was defined as the maximum number of items (digits/words) recalled in the correct order. In our second task, SD, the comprehension and consequent memory for the individual sentences should in no way affect the ability to remember numerals, since remembering the gist of the sentence would not be useful in generating digits. If the relationship between this reading span measure (SD) and reading comprehension measures still hold, then one could consider (as Daneman and Carpenter did) that both these span tests are indexing a memory process that is functionally related to reading comprehension. Thus, good reading comprehenders, by using better and more efficient strategies when reading the individual sentences and, consequently taking up less of the total WM space, would leave more capacity for storage of the products, i.e, the to-be-remembered word or digit.

However, the main purpose of this pilot study was testing whether the relationship between these span measures and reading comprehension is dependent on the fact that the secondary task also involved reading, as Task Specific Theory argues (Daneman and Carpenter, 1980). It should be noted that this explanation assumes that the secondary concurrent task used with the predictor measure, the reading span task, must be highly related to the criterion task, i.e., the reading comprehension task. Both reading spans, measured by the sentence-word and sentence-digit tasks, would be assumed to reflect differences in residual WM capacity because of differences in WM capacity independent of task proficiency.

An alternative explanation, however, is that the reading span may index stable and abiding individual differences in WM capacity independent of the processing task, i.e., the Trait explanation. This explanation assumes that embedding the memory span index in any secondary task that requires heavy processing beyond the span task would reflect individual differences in WM capacity important in higher level functioning.

Therefore, the subjects performed a third test, an operation-word (OW) test in which the secondary task involved performing simple arithmetic operations (e.g., $(3 \times 4) + 11 = \underline{\quad}$) followed by a to-be-remembered word. If the correlation between performance of the reading comprehension task and the number of words recalled in the OW task is still significant, this suggests individual differences in WM capacity are independent of the specific task used as a concurrent task to the span measure.

In fact, the operation-word (OW), sentence-word (SW) and sentence-digit (SD) spans all correlated similarly with a measure of reading comprehension, $r(35) = .41, .36, \text{ and } .49, p < .02$ respectively. The correlations between OW, SW and SD spans and verbal SAT scores were also significant, $r(35) = .38, .39$ and $.50, p < .02$ respectively.

These results clearly failed to support Task Specific Theory and indicated that these span measures of WM capacity were stable and independent of the type of processing task in which they were embedded. The use of a span task involving strings of arithmetic operations followed by a to-be-remembered word, allowed the memory span test to be embedded in a task that, while probably verbal, requires a different set of strategies than reading. The task nevertheless would induce considerable processing demands concurrent with the span measure. Hitch (1978) found that solving mental arithmetic problems utilized processing strategies, which included a temporary storage of initial and interim information. However, the processing strategies for reading sentences is inherently different than those used in solving numerical operations mentally. Thus, individual differences in the WM index may indicate stable and abiding differences in WM or total work space in the central executive as proposed by Baddeley and Hitch (1974). By this logic, some people may be better reading comprehenders because of larger WM capacity, NOT have more available WM capacity because they have more efficient reading skills as Task Specific Theory argues.

This study was replicated and extended in two major studies funded by the current grant (Turner & Engle, 1989). In the first experiment 243 subjects were tested on four complex memory span tasks, two simple span tasks and the Nelson-Denny reading comprehension test. The background task in the complex spans was either calculating the results of a string of arithmetic operations or reading a sentence. The to-be-remembered items immediately followed the operations and sentences and were either words or digits. Thus, the four complex span tasks were Operation Word, Operation Digit, Sentence Word, and Sentence Digit. The

two simple span tasks differed in whether the to-be-remembered items were words or digits. The criterion tasks were the Nelson-Denny reading comprehension test and the verbal and quantitative portion of the Scholastic Aptitude Test (VSAT and QSAT).

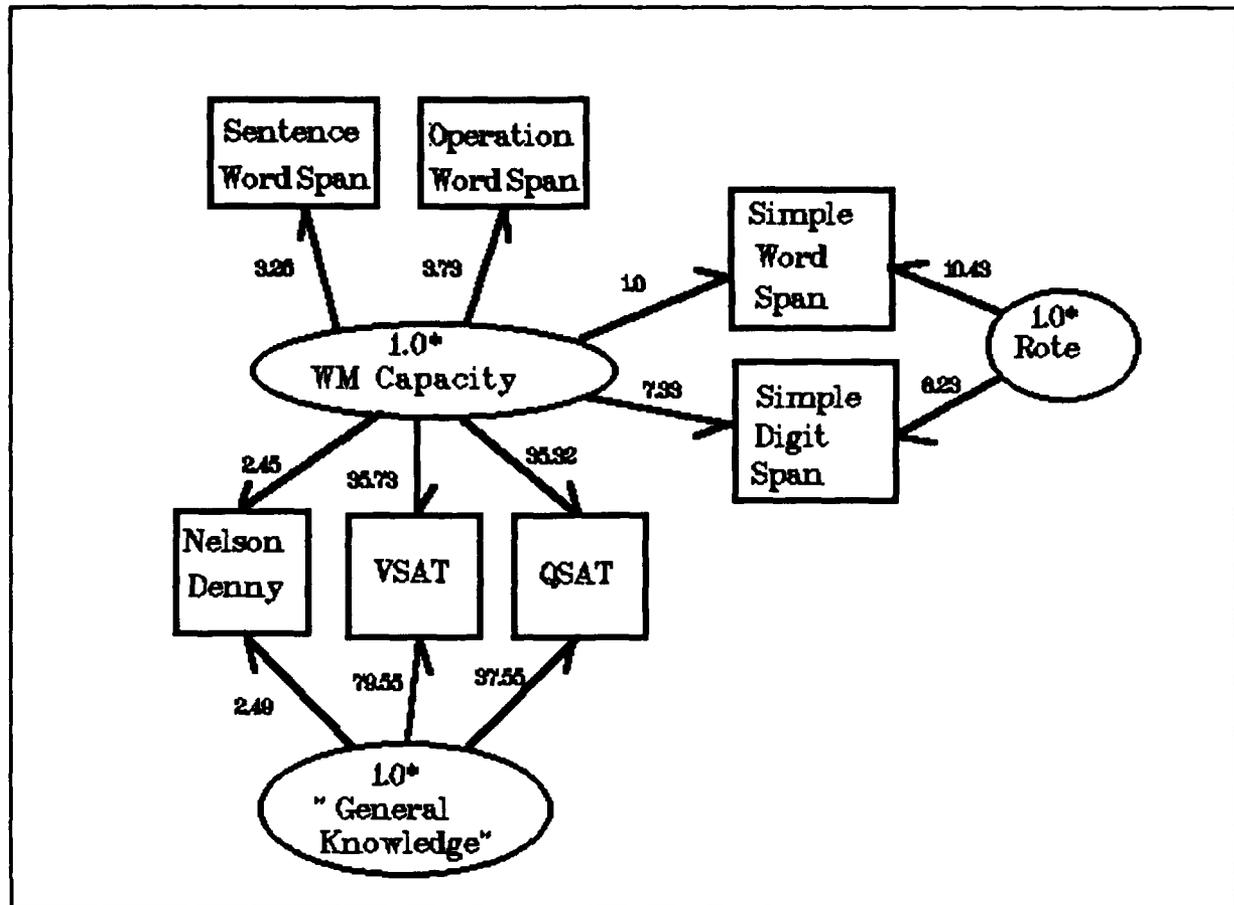
The large number of subjects were tested to allow us to test for a possible artifact in the earlier study. Recall that the Operation Word and the Sentence Word task were equally predictive of reading comprehension. This could have been due to an artifact that would allow Task Specific Theory to still be correct. The Operation Word-Reading Comprehension correlation could have been an accidental correlation resulting from the fact that verbal and quantitative skills tend to be correlated. Thus, a good reader, according to Task Specific Theory, would have efficient reading skills, leaving more residual working memory capacity for storage than would be available for a poor reader. This same good reader, when performing the Operation Word task would likely have efficient arithmetic skills since verbal and quantitative skills are correlated. Thus, the good reader, also being good in arithmetic, would have more residual WM capacity to represent the span words. If this artifact is responsible for the relationship between Operation Word and reading comprehension, then the relationship should disappear when quantitative skills are partialled out or when we look at just people who have a great disparity between their verbal and quantitative SAT scores. We ran the large number of subjects to allow us to do these analyses.

The results were like those of the earlier study in showing that Operation Word and Sentence Word equally predicted reading comprehension and this relationship remained when the variance due to QSAT was partialled out of the relationship. This argues strongly against the Task Specific Theory of the relationship between WM capacity and higher level cognitive tasks. It also demonstrates that the relationship between the operation Word task and reading comprehension is not an accidental correlation because of the high correlation between verbal and quantitative skills. The results support the idea that working memory capacity is a more general characteristic of the subject than argued by Daneman & Carpenter (1980).

However, the results were unlike the other study in several respects. For one, this study included the two simple span tasks and neither of them correlated with the criterion reading comprehension measures. All of the correlations between the span measures and the reading comprehension criterion measures were somewhat smaller in this study than those obtained in the previous or in subsequent studies. And, while the

complex digit spans (Operation Word, and Sentence Word) both significantly correlated with the criterion measures (Nelson-Denny and VSAT), the correlations were about half the correlations of the complex word spans. This finding is similar to the finding of Palmer, MacLeod, Hunt and Davidson (1985) that reading comprehension is predicted by information processing measures when those measures involve words but not when they involve letters.

A subsequent Analysis of Covariance Structures (Bentler, 1985) of the data from Turner & Engle (1989), by Cantor (see Appendix) supports the model below in which there is a unitary WM with a limited capacity, that will constrain performance on any task that requires attention. Scores on all the tasks are viewed as reflecting both WM limitations, and the extent to which performance can be aided by processes that are less dependent on this global capacity. Thus, performance on the simple span tasks is viewed as a manifestation of both capacity limitations, and the ability to engage in chunking, rehearsal and elaboration, while scores on the Nelson Denny and SAT's reflects capacity and subjects' general knowledge. For the complex span tasks, reading sentences aloud or solving simple arithmetic equations is expected to significantly reduce or eliminate the ability to engage in elaboration and rehearsal, and is not predicted to require much general knowledge. Consequently, scores on these tasks are viewed as direct indicators of WM capacity. Equations describing this model, and the data from Turner & Engle (1989) were submitted to a goodness of fit test using the GLS approach provided in the EQS statistical package (Bentler, 1985). The results showed that the data can be adequately described by the model ($\chi^2[11] = 8.6, p = .66; NFI = .99$), thereby lending further support for the notion of a general working memory capacity.



In general, the findings of this study support a thesis that working memory is important in higher level cognition and that it is measurable by relatively simple laboratory tasks. It further supports the idea that we *don't have to think about a different measure of working memory for each person-task interaction.*

What is the relationship between STM measures and the complex span tasks?

We don't know what the relationship is between these complex tasks and more standard measures of STM and what it is about the complex tasks that allows the relationship between the measure of working memory and reading comprehension to surface. Variables important to the simple digit and word span tasks have been well studied and specified over the past 25 years but we know very little about the variables important to the complex span tasks. If different variables are important and some variables lead to different effects with the simple and complex tasks, then we can argue that they are reflecting different store or processes. But if the same variables operate similarly for the two types of tasks then we can argue that they are

simply different ways of looking at the same beast. We have addressed those issues to some extent in work performed during the current funding period and hope to further address them in the future.

Other evidence that the Operation Word span task behaves like the Sentence Word span task comes from a study in which the difficulty of the background task was varied (Turner & Engle, Experiment 2). The basic finding was that the highest correlation between both the complex span measures and reading comprehension occurred at a moderate level of difficulty of the background task. The correlations were lower when the background task was either very simple or very difficult.

What is the relationship between the traditional STM tasks and the complex span tasks?

One set of questions motivating this research asked why the traditional measures of STM seem to do less well in predicting performance in higher level cognitive tasks, while the newer working memory measures predict performance very well. By traditional STM measures I mean the digit and word span, which typically are not credited with predicting performance in more complex tasks. Low correlations have commonly been found between digit span and measures of higher level cognitive abilities, such as reading comprehension (Daneman & Carpenter, 1980; Masson & Miller, 1983; Chiang & Atkinson, 1976). In addition, the span index has been found unstable and the least reliable subtest on psychometric measures of cognitive ability (Wechsler, 1958). In fact, Wechsler argued that only low spans are useful in predicting individual cognitive abilities, since they are invariably correlated with mental retardation (from Dempster, 1986).

However, strong correlations between simple digit or word span and reading comprehension measures are occasionally reported in the literature and we have occasionally observed them in our own work. Let me briefly describe two studies that have found conflicting patterns of relationship between digit span and the SAT. Chiang & Atkinson (1976) measured digit span in college students and found no relation between digit span and SAT. In fact, the correlations were slightly negative. Dempster & Cooney (1982) also measured digit span in college students and found a correlation of nearly .75 with digit span and the two SAT scores. Any number of variables could account for these differences. Two possibly important ways the studies differ is in the nature of presentation of the digits and in the makeup of the subject sample. Chiang & Atkinson used visual presentation by a computer monitor and the subjects typed in their recall. Dempster & Cooney used auditory presentation and the subjects orally recalled the digits. Both mode of presentation and

mode of recall have been shown to be important variables in STM tasks (including serial recall of short lists) but these variables are typically ignored when researchers study the relationship between span and higher level criterion measures like SAT or reading comprehension measures. Another possibly important variable that differs between the Chaing & Atkinson and Dempster & Cooney studies was the nature of the subjects. Chaing & Atkinson used Stanford undergraduates and the mean total SAT for their sample was 1273. Dempster & Cooney used Texas A & M students and the mean total sat for their sample was 1026. This 247 point difference could be important if the relationship between digit span and SAT does not hold over the entire range of SAT scores.

It is well known that simple span scores, at least digit span, are commonly unreliable and unstable. While our studies have done some assessment of reliability, it has been relatively primitive. Most of the studies have looked at reliability within a session and the reliabilities have ranged from .81-.89 for simple word and sentence word task. One study was performed on the stability of the operation word span and simple word span scores over one week. This analysis showed a stability index of .8 for the operation word span score and .71 for the simple word span score. We plan to continue our concern for reliability of measurement and hope to do more of this uninteresting but necessary analysis of our instruments.

Studies in our lab have occasionally resulted in significant and rather large correlations between simple spans (usually word span) and criterion measures of reading comprehension. It is important to know why the simple spans sometimes predict higher level comprehension and sometimes do not. On the other hand, the relationship between the complex span measures of WM capacity (Sentence Word, or Reading Span and Operation Word Spans) and reading comprehension (Nelson-Denny or VSAT) is much more stable. This correlation may vary slightly depending on the study (typically about .40-.60), but it regularly occurs. This is remarkable given the very small range of scores on the complex span tasks. When the span score is defined as the longest list that the subject gets perfect on 2/3 of the trials, the Sentence Word and Operation Word, commonly gives spans of 2-4. Even when we analyze the total number of words in perfect trials, the range of scores is much more restricted than for simple span measures. The reliabilities for the complex and simple spans are generally comparable in our studies with the range being .80-.89 in analysis of alternate trial-split half reliability.

So the question is why the simple spans sometimes do and sometimes don't predict reading comprehension and the complex spans almost always do. At a theoretical level, this question translates into whether these two types of measures reflect the same or separate systems (WM and STM). Since the publication of Daneman & Carpenter (1980), it has been assumed by many researchers that their measure was tapping something uniquely different from what was tapped by the simple digit or word span. This may or may not be the case and some of the work performed here was designed to find out.

Many researchers in the field have essentially replaced the concept of a passive STM with the active, more flexible, concept of WM, assuming that, otherwise, they are describing the same hypothetical construct (e.g., Howard, 1983). However, several researchers have viewed these two systems separately, i.e., maintaining the passive STM storage limitation and adding an active WM processing limitation (Klapp, Marshburn, & Lester, 1983; Brainerd & Kingma, 1984, 1985; Case, Kurland, & Goldberg, 1982; Reisberg, Rappaport & O'Shaughnessy, 1984). For example, Klapp, et al. (1983) tested whether the simple span capacity limit found in passive STM tasks is related to the complex span limit found in information processing tasks reflecting a WM. They used the missing-digit task assuming that the task requires some form of memory for presented digits while searching for the missing digit, and assuming that the task did not require order information. Variables known to affect recall in STM span and/or WM span tasks, such as rhythmic grouping and acoustic/articulatory interference, were manipulated. They found that rhythmic grouping did not affect the missing-digit task. On the other hand, the use of rhythmic grouping led to the usual effect of increased serial recall in a typical STM digit span task. In addition, rhythmic grouping led to better recall even when the auditory component of memory span was eliminated with articulatory suppression. They argued that when articulation was suppressed, recall is assumed to be based on some residual (nonauditory) component of memory span, such as the WM central executive component posited by Baddeley and Hitch (1974). Klapp, et al. (1983) made the point that although rhythmic grouping improved recall in span tasks that have been used as measures of STM and the storage component of WM, there was no effect of grouping in the missing-digit task, a task which they argued clearly requires a "memory source." Therefore, they suggested the memory source was a "working memory" that was not flexibly divided between processing and storage, but was used only for processing.

Brainerd and Kingma (1985) also questioned the validity of considering these two systems, STM and WM, as "one system." They questioned the basic assumption held by the "one system" hypothesis that STM (as measured by span) and information processing (as measured by strategic or non-strategic measures) draw upon a common pool of scarce resources, usually called WM capacity. They argued that STM is specialized for storing and retrieving recent information while WM is specialized for processing information, including storing and retrieving products of the current processing. They found that the results of several different reasoning tasks (reflecting active information processing) showed no relationship with tasks requiring memory for critical background facts (reflecting storage in a passive STM), and argued that the STM measure for critical background facts, and the measure of the processing required for reasoning problems were independent measures reflecting two different underlying systems. They concluded that there are resources supporting a STM that is used for storage and retrieval of long term memory representations, and there are resources supporting a WM used for processing active information only, and that these resources do not overlap.

A WM system, such as described above, would only process active information, and would not store or retrieve recent (but inactive) long term memory information. Therefore, WM capacity could not be flexibly divided between processing and storage of interim products, since these products do not remain active and are reactivated only when needed. This conceptualization of WM (Klapp, et al., 1984; Brainerd, et al., 1985) suggests that we have a limited WM capacity system for processing information (perhaps as a central controller), which cooperates with a limited STM capacity system used for storage. Consequently, in considering why the complex spans correlate more with individual abilities than do the simple spans, we must be aware that WM and STM may be two completely different systems. Then, of course, the simple digit- and word-spans (reflecting a STM) and the complex memory spans (reflecting a WM) would be expected to correlate differently with any particular measure of higher level cognitive skills. For example, although STM span has consistently shown performance deficits in children as compared with adults, Chi (1976) found that these deficits are better explained as a deficit in processing strategies and processing speeds (i.e., a WM function) as well as a limited knowledge base in long term memory (LTM). Thus there is the possibility that the STM span and WM span measures are reflecting two entirely different limited capacity systems.

However, there is also the possibility that they are simply measuring different components (with different limitations) of the same system. For example, they could be measuring the different functional components of a WM system as defined by Baddeley and Hitch (1974) (i.e., central executive, an articulatory loop and a visuo-spatial sketch pad), suggesting there may be different measurable "capacities" underlying STM and WM span measures. Although the central executive flexibly divides a single undifferentiated resource pool between processing and storage, the other two slave components may each have different underlying storage resources. For example, Baddeley, Thomson and Buchanan's (1975) findings suggested that the function of the articulatory loop is maintaining verbal information using serial processing. Later, Baddeley (1979) argued that the loop was the WM component specifically used for rote rehearsal. Serial processing of verbal information, i.e., rote rehearsal, is required in the simple digit task and is often but not always required in the word span task. This suggests that perhaps the simple span task is best thought of as measuring the articulatory loop component of the WM system, and NOT the central executive. If so, then, a different underlying resource (mechanism) may be reflected by the simple span (the articulatory loop), than the resource measured by the complex span (i.e., the central executive).

There are several strategies that can be used to determine whether the two types of tasks reflect common systems. One way is to see what manipulations will make the simple spans more like the complex spans in their ability to predict reading comprehension. Another way is to see to what extent performance in the two types of tasks (simple and complex spans) is affected by the same variables and in the same direction and to what extent the correlations with criterion measures are affected by the variables.

We have used both strategies in the current project with some success. For example, one study manipulated whether the 96 subjects were asked to give serial or free recall in simple word span and sentence word span tasks and looked at how the correlations with the VSAT were affected by this variable. The mean span scores and the standard deviations were not affected by this manipulation for either word or sentence span. And, while the correlation between sentence span and VSAT was not affected by recall instructions (.45 for free and .47 for serial), the correlations for the simple word spans was significantly affected by this variable with correlations of .17 for free and .27 ($p < .05$) for serial. This change from .17 to .27 is not remarkably high but several other studies in which we required serial recall of the span items resulted in correlations for simple

word span as high as those for the sentence or reading span. This needs to be further explored particularly since several recent models of working memory seem to give considerable theoretical significance to order information (Monsell, 1984; Klapp, 1987; and Schneider & Detweller, 1987).

We conducted another set of studies to see whether variables known to be important in the simple span task are also important in the sentence word span tasks. The extensive work done since 1960 on STM has discovered numerous variables that influence performance. Some of these variables have been argued to also have theoretical importance to the new view of working memory. For example, acoustic similarity and word length are assumed to reflect the representation in the articulatory loop of Baddeley & Hitch (1974). Word length has a highly reliable effect on simple word span tasks with more short words being recalled than long words (Baddeley, Thomson & Buchanan, 1975). We have manipulated word length in four studies, three of which have been completed.

All studies have shown that word length has the same effect in the complex word span task as it has in the simple word span task. In both types of tasks, more short words are recalled than long words. The remarkable thing about this finding is, again, the range of scores is so small for the complex span scores that there is not much room for the word length variable to have its effect. But word length does have a small but highly reliable effect on the complex span task, regardless of whether it involves the subject recalling the last word of the sentence as done by Daneman & Carpenter (1980,1983) or whether the word to be recalled follows the sentence and is unrelated to it or whether the complex span task is the operations word task.

Let me detail this last study in some detail since it further makes the point that the background portion of a working memory task does not necessarily have to be reading for the correlation with comprehension to occur. Each of 80 subjects was tested on both a complex operations word span and a simple word span. The words used for both spans were short (one syllable) for half the subjects and long (3-4 syllables) for half the subjects. The operations were presented in the form of a question as is shown by the following examples: Is $(7 \times 2) + 3 = 17$? Is $(10 / 2) - 1 = 6$? The subject was to simply respond yes or no at the end of each operation depending on whether the number on the right of the equation was a correct result of the operations on the left of the equation. The operations were generated by computer, presented on the

monitor of the computer and were read aloud by the subject. A word was presented following each operation which was also read aloud. At the end of each set of operations the subject was cued to recall the words.

As with all of our studies, we scored the span recall in several ways and, as is typical, the conclusions were not specific to the method of scoring and we report the analysis of the absolute score. This is the number of words from those trials with perfect recall. The number of words from perfect trials was a function of task and word length. Performance was better in simple span than operation span task and more short words were recalled than long words. Further, the interaction between these two variables was significant. Word length was important for both tasks but had a larger effect with simple span than operation span.

These findings suggests that both simple and complex spans are, to some extent, measuring an articulatory representation. Our view in the original proposal was that the complex span might be a measure of WM storage without the benefit of articulatory coding and that this was possibly a better predictor than a measure that included the articulatory representation. That now appears to wrong. The extent to which the complex spans are affected by the same variables that affect simple spans needs to be explored further.

One other variable that has been shown to affect recall in simple span experiments is suppression of the articulatory coding. This is done by having the subject repeatedly articulate some simple word or phrase such as "the, the, the,..." or "1, 2, 3, 1, 2, 3,..." while performing a memory span task.

We recently completed an experiment in which we had subjects perform an articulatory suppression while also performing a simple word span task and an operations span task. We made the operations span task simpler because a pilot study had shown that subjects could not do a complex operations task while also articulating the three letters, A-B-C. For the operations span task, the subject was shown arithmetic strings of the form " $Is (5 \times 2) = 10?$ " followed by either short or long words. Baddeley and his colleagues (Baddeley, 1986) have argued that articulatory suppression will eliminate the word length effect because the individual can not do irrelevant articulation and code the to-be-remembered words in an articulatory format. Contrary to Baddeley's predictions, the results of our study showed not only a word length effect with the simple span, but also with the complex operations word span. Further, the size of the word length effect was identical for the simple and complex spans.

Our conclusion from this study is that there are multiple codes responsible for the word length effect. Articulatory suppression probably does eliminate covert articulatory rehearsal but it does not eliminate the representation of phonological and articulatory codes at a deeper level than sub-vocalization. It may be that the working memory limitation that is important to higher level cognition, at least for those tasks that are verbal in nature, centers around limitations in either the number or the length of time that we can represent these deeper level phonological or articulatory codes.

Another study completed this year tested whether working memory capacity is important in following directions. This was part of a developmental study involving 40 subjects at each of four ages, 1st grade, 3rd grade, 6th grade and college students. The subjects were tested on a simple word span and a sentence span with the sentences adjusted to be appropriate difficulty for the group. The criterion tasks were reading comprehension normed for the group and a following directions task. The directions were chosen to cover a number of behaviors requested (from 1 to 6) and to vary the number of qualifiers of those behaviors (also from 1 to 6).

The basic findings of this study were that both simple word span and sentence span tasks significantly predicted comprehension and following directions performance. However, the relationship was slightly higher between the criterion measures and the sentence span and this was generally true regardless of age group. In other words, the relationship between working memory capacity, as measured by the span measures, and the higher level tasks was not different for the first graders and the college students.

CONCLUSION

The studies briefly summarized here lead to several conclusions about individual differences in working memory and the role of those individual differences in real world cognition. If we define working memory by what is measured in a task like the complex span task, individual differences in working memory capacity does not depend on that measurement being taken while the individual is performing some version of the criterion task. We originally thought that of working memory as a unitary construct independent of task. We now believe that the important individual variation in the complex span tasks may be peculiar to other verbal tasks requiring working memory. That conclusion, however, awaits the conclusion of a series of studies

using spatial components of both the background and span tasks. It is clear that the complex span tasks, both sentence span and the operations span, will lead to effects of word length and articulatory suppression that are quite similar to those obtained with the simple span task. This suggests that some form of phonological coding, or at least some other coding depending on the length of the word, is used in both simple and complex tasks. Whether there is individual variation in that coding for the complex tasks and whether that covaries with individual differences in the verbal criterion tasks like VSAT remains to be studied.

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