The Reading Span Test and its predictive power for reading comprehension among young and old adults

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THE READING SPAN TEST AND ITS PREDICTIVE POWER FOR READING COMPREHENSION AMONG YOUNG AND OLD ADULTS

by

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Bachelor of Science
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May 2002

A thesis submitted in partial fulfillment of the requirements for the

Master of Arts Degree in Psychology
Psychology Department
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Graduate College
University of Nevada, Las Vegas
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Examination Committee Chair

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ABSRACT

The Reading Span Test and its Predictive Power for Reading Comprehension Ability among Young and Old Adults

by

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Although many researchers appear to agree on the usefulness of both simple and complex span tasks, many disagree on the specifics of how or why they measure working memory. The following paper considers competing theories of the relationship between working memory tasks and higher order cognitive function. Consideration is given to simple and complex measures of working memory, various theories about them, and theories based on research within the cognitive aging domain. Subsequent discussion reports the findings from a new study aimed at resolving disagreements about the relationship between lower and higher level cognitive abilities in college-age and older adults.
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CHAPTER 1

THE READING SPAN TEST AND ITS PREDICTIVE POWER FOR READING COMPREHENSION AMONG YOUNG AND OLD ADULTS

The field of psychology has historically relied on the use of hypothetical models to illustrate concepts that are difficult, or impossible in some cases, to describe theories about various mental phenomena. Within the sub-specialty of cognitive psychology, models have been useful in demonstrating the structure and function of human memory. Although it is becoming increasingly commonplace for researchers to validate or invalidate hypothetical models of memory with the use of sophisticated research technology, such as Functional Magnetic Resonance Imaging, scientists have traditionally implemented basic tasks in research investigations, which are thought to tax related internal cognitive processes.

The present paper discusses key hypothetical models of memory dating back to the time of William James up to the present. Particular consideration is given to current theories about the nature of working memory, a short-term memory store that is thought, by some, to be involved in higher-order verbal cognitive processes, such as reading comprehension. The structure and functional abilities of working memory are hypothesized to be measured by a variety of memory-related tests. Tests of the capacity of working memory have, historically, included presenting subjects with series of digits or words to remember and subsequently recall. In the 1980's, however, a new measure of
working memory was introduced, the Daneman and Carpenter reading span task (Daneman and Carpenter, 1980), which required subjects to read aloud a sets of sentences, store the final word of each sentence, and later recall the final words. For memory researchers, the appeal of such a task was the storage and processing component, which appeared to directly correspond to the hypothetical construct of working memory.

This new measure of working memory was met with general enthusiasm among cognitive psychologists and numerous studies were, and still are, conducted to understanding if and how it might correlate with higher-levels of cognition (see Daneman & Merkle, 1996 for a review). Friedman and Miyake (2004), for example, sought to determine the explicit means by which the reading span task might be used in predicting reading comprehension among college-age adults and, likewise, how reliable the measure was at doing so. Their data indicated that how the task was administered significantly impacted the reliability of the measure.

The present study is aimed at further investigating the findings of Friedman and Miyake (2004) among both young and older adults. It has been well-documented in the cognitive aging literature that healthy older adults (ages 65+) exhibit declines in cognitive function, including their speed of cognitive processing (Salthouse, 1996) and working memory capacity (Meguro, Fujii, Yamadori, Tsukiura, Suzuki, Okuda, & Osaka, 2000), as indicated by the use of the Daneman and Carpenter reading span task. It is, therefore, imperative that a detailed analysis of the properties and predictive ability of the reading span task be undertaken in order to test the validity and reliability of theories of cognitive aging. This study attempts to accomplish that goal by investigating: (1) the reliability of the reading span task, as compared with other commonly used working memory span
tasks, in predicting reading comprehension among young and healthy older adults, (2) if the administrative procedure may impact the reliability of the tasks in predicting higher-order cognitive processes, (3) potential strategies that participants may use to complete working memory measures.
CHAPTER 2

THE READING SPAN TEST AND ITS PREDICTIVE POWER FOR READING COMPREHENSION AMONG YOUNG AND OLD ADULTS

Working Memory: Historical Antecedents and Current Theories

William James is credited with first distinguishing between short term and long term memory stores. In his massive, two-volume *Principles of Psychology* (1890), James declared that all conscious experience requires memory. He described two types of memory: primary and secondary memory. According to his model, primary memory retains information immediately observed in the environment. Secondary memory, alternatively, is a longer-term store that contains permanent memories, some of which are available to consciousness and others that are not. This description of memory has come to be known as the dualistic theory of memory. Because of the influence of behaviorism and its emphasis on observable phenomena in psychological thinking of the first half of the twentieth century, James’ ideas did not exert their influence on theories of memory until the 1960s, at which time the cognitive approach to psychology became more prominent.

Waugh and Norman (1965) later attempted to expand and quantify the properties of James’ dualistic theory. They achieved this by studying participants’ ability to retain and recall series of numbers. Based on data obtained from these studies, they postulated that information in primary memory may either be retained through rehearsal or forgotten
due to interference. If the information was rehearsed in primary memory, then the information may be sent to secondary memory for long-term storage. Whereas James’ dualistic theory of primary and secondary memory provided the foundation for theories of memory, the Waugh and Norman work provided the evidence needed to support the theory.

This model, however, was soon criticized because it failed to specify how information traveled from the environment into memory and, moreover, how the information was further sent to secondary memory. In an attempt to resolve these shortcomings, a newer model of memory, which became the modal model of memory, was proposed. Atkinson and Shiffrin’s (1968) modal model of short term memory postulated a sensory register, a short-term (or primary) memory store, and a long-term (or secondary) memory store. According to this model, environmental information is initially processed in the sensory register, consisting of iconic and echoic sub-stores, where it is either ignored or held for further processing by the short-term memory store. Information could then either be retained briefly in the short-term memory store and subsequently forgotten, or it could be further processed to the long-term memory store for later retrieval. In addition to its role as an antechamber to long-term memory, the short-term memory store was also postulated to be involved in higher-level cognitive functions such as critical thinking and reading comprehension (Atkinson & Shiffrin, 1968).

This simple model of memory was later expanded by Schacter and Tulving (1994). The new model of memory consisted of five interconnected systems: procedural memory, perceptual representational system (PRS), primary memory, episodic memory, and semantic memory. These different types of memory stores roughly corresponded to the
Atkinson and Shiffrin model, such that PRS was construed as the sensory memory, primary memory roughly equated to short-term memory, episodic and semantic memory comprised long-term memory, and the new component, procedural memory, contained information about learning, simple conditioning, and motor and cognitive skills. Although strong evidence has been found in support of this newer model of memory, there appears to be some disagreement about the distinguishing characteristics of episodic and semantic memory (Craik, 2000) and the nature of primary memory. For the purposes of this paper, I will focus on the debate about the nature of primary memory.

This modal model of memory was later challenged by Baddeley and Hitch (1974) who proposed a more dynamic model of short-term memory, called “working memory”. Similar to the Atkinson and Shiffrin model of memory, the working memory model proposed that, following sensory encoding, information was processed in a short-term memory store that shared information with and passed information along to a longer term memory store. Both models likewise proposed that some higher-order processing occurred in the short-term memory store, particularly language processing and comprehension. The key difference, however, was that the working memory model provided greater specificity as to how short-term memory was involved in higher order processing as a temporary, limited-capacity storage space, in which information is retained and manipulated into meaningful data units for further processing in long-term memory (Baddeley, 1986).

The original working memory model proposed that, following encoding in sensory memory, information was further processed by the central executive. The central executive was hypothesized to carry out a number of memory-related tasks, including
attentional control, allocating visual information (i.e. symbols and mathematical equations) to the visuospatial sketchpad, verbal information to the phonological loop (i.e. language and sounds), and combining information from the subcomponent stores with information from long-term memory.

Figure 1. Baddeley and Hitch (1974) model of working memory.

Although the Baddeley and Hitch (1974) three-part working memory model proved sufficient in explaining some memory-related phenomena of the times (such as the ability to store and recall words in memory), it still required a greater specificity in regards to the duties of the component parts. In light of newer research (i.e. Daneman and Carpenter, 1980) it became doubtful that the central executive, which itself was limited in capacity, could necessarily account for the lion’s share of the functional properties of the working memory system. This speculation inspired new approaches to measuring working memory and, consequently, newer models of memory (detailed later). Whereas previous research relied on data obtained from neuropsychological patients and word/letter span tasks, newer approaches to memory attempted to measure how more complex sets of information, such as sentences, were stored and processed in working
memory (i.e. Daneman and Carpenter, 1980). The focus of these studies, then, became the amount of information that could be stored in memory, or working memory capacity.

Inspired by newer findings through the use of more sophisticated measures of memory, a new theory of working memory was proposed by Just and Carpenter (1992) which emphasized the function of the central executive component of the Baddeley and Hitch (1974) model of working memory but eliminated the modality-specific sub-stores. This model has thus come to be known as the “unitary” or “resource sharing” model of working memory. According to their view, the efficiency with which an individual completes span measures is contingent upon the amount of cognitive resources available in working memory. For example, readers with good reading skills will likely consume less cognitive resources, enabling them to use additional working memory space to remember the words. Accordingly, these “high-span” individuals would be expected to outperform “low span” individuals with less efficient reading skills on comprehension measures.

The more complex measures and model of working memory provided a framework in which Baddeley could revise the original vision of working memory with greater specificity. Baddeley (1996) revised the model by assigning greater attentional responsibility to the central executive and hypothesizing a new component to the model, the episodic buffer. The episodic buffer, thus, was thought to combine information from the visuospatial sketchpad and phonological loop, while simultaneously retrieving pertinent episodic information from long-term memory. It may be noted that this latter function, retrieving episodic information from long term memory, evokes the episodic
nature of long-term memory proposed by Schacter and Tulving in their model of memory (1994).

The visuospatial sketchpad is thought to aid in spatial navigation, solving visuospatial problems, and, to some extent, maintaining mental representations of visuospatial information during reading (Baddeley, 2002, 2003). Within this memory store, visual and spatial information are mediated by the sketchpad, via the senses or long-term memory (Baddeley, 1996; Baddeley & Hitch, 1974). Direct support for the visuospatial sketchpad has been difficult to obtain because the construct was vaguely defined to begin with (Logie, 1995). Logie (1995), however, discussed two possible lines of evidence for the visuospatial sketchpad: (1) the “visual similarity effect” and (2) some evidence suggesting a common short-term memory system for visual and spatial material.

The visual similarity effect refers to subjects’ difficulty in recalling visually presented items that are visually similar (Logie, 1995). This effect is reported to be particularly evident in studies that include letters and numbers as the experimental stimuli (i.e. Logie, 1995, Frick, 1998). Frick (1998), for example, found that subjects had confusion recalling the number 9 when it was visually presented in a block font because they confused it for the number 8. When 9 was presented visually in a curved font, however, the effect seemed to disappear.

There also appears to be some evidence in support of a common visual and spatial short-term memory store, however this evidence is rather weak, and although it is more commonly found in neuropsychological populations (Logie, 1995), it is difficult to measure in normal adults. In light of the weak direct evidence for a common visual and spatial memory store, Logie (1995) argues that a common memory store may rely on two
interdependent sub-components: the visual cache', a passive visual system responsible for storage of visual information presumably including graphemic text information, and the visual scribe, an active visual system responsible for spatial information.

The phonological loop, responsible for auditory processing, is composed of two sub-unit processors: the articulatory rehearsal system and the phonological store. The relationship between these two phonological components is such that the operation of one unit is dependent on the other. That is, information in the phonological store will decay after a period of two seconds, unless refreshed by the articulatory rehearsal system. Sub-vocal rehearsal of new information is one means by which information in the phonological store may be refreshed. There are two lines of evidence in support of this theory: (1) the phonological similarity effect and (2) the word-length effect.

The phonological similarity effect refers to subjects' better recall of words that are phonologically similar. For example, Baddeley (1966) found that subjects recalled words such as man, cat, map, cab, can better than words like pit, day, cow, sup, pen. Interestingly, in the same study, he found that this effect does not appear to hold for words that are similar in meaning. Thus, the effect occurs for both related and unrelated sets of words. Baddeley's conclusion was that this effect occurs because similar sounding words are easier to subvocalize. There are to date two viable explanations for the phonological-similarity effects. The first explanation posits that similar sounding words cause a quicker decay of the phonological codes during rehearsal and recall (Posner & Konic, 1966). The second explanation for the phonological similarity effect is that during recall the partially degraded codes of similar items are more difficult to reconstruct for recall (Hulme, et. al., 1997).
The word-length effect describes participants' better recall of words that contain fewer syllables. The idea here is that smaller words require less subvocal rehearsal and are, consequently, easier to recall. Studies assessing how well the phonological loop model predicts word-length effects on word span tasks have measured articulatory duration, or how long it takes participants to pronounce a word. As outlined by Mueller, Seymour, Kieras, and Meyer (2003), there are five commonly used approaches to measuring articulatory duration, each of which may bring about different outcomes. The first approach is to measure the amount of time it takes participants to pronounce a word aloud in isolation (Baddeley, et. al., 1975). The second approach to measuring articulatory duration is to record the total time it takes participants to repeat two or three words several times (Lovatt, et. al., 2000). A third approach is to measure how long it takes individuals to articulate lists of words that are presented visually (Caplan & Waters, 1994). A fourth approach is to measure how long it takes participants to produce sequences of words during final recall (Cowan, et. al., 1997). The final approach to measuring articulatory duration is to measure the mean duration per word for a set of words from lists that vary in length and sequence (Mueller, et. al., 2003).

Evidence in support of the phonological loop interpretation of word length effect appears mixed. Caplan, et. al. (1992) found that recall accuracy was higher for long words than for short words, thus contradicting the results of previous word length effect studies. Based on these results, they suggested that word length effect may stem from speech planning times, as influenced by the complexity of phonemes and syllables. In a follow-up study, however, Caplan and Waters (1994) obtained opposite results, and recall accuracy was better for shorter words than longer words. Similarly, Cowan, et. al. (1997)
found that recall accuracy was weaker when subjects read long words aloud compared with reading short words aloud. Based on these results, they suggested that perhaps the phonological loop model should take into account interference in recall accuracy.

Nevertheless, in an experiment conducted by Cowan, Nugent, Elliot, and Geer (2000) the opposite effect was found under different conditions. Essentially, the results obtained all suggest that when modifying presentation order or altering the testing scenario, different results may be obtained. Baddeley, Chincotta, Stafford, & Turk (2002) later revised the theory and argued that the effect may result from both articulatory suppression as well as forgetting.

Recently, Mueller et. al. (2003) attempted to resolve the mixed findings from previous studies using a new measure of phonological similarity, PSIMETRICA Phonological SIMilarity METRIC Analysis. This program records and measures aspects of spoken words that are similar in their phonological properties with reported greater specificity than previous measures of phonological similarity. Although time may tell if PSIMETRICA is as reliable as the authors report, the results of the Mueller, et. al. study do offer new insights into the study of verbal memory. Of critical interest, they found conflicting results with previous measures of phonological similarity judgments (i.e. Caplan and Waters, 1994), such that the degree of difficulty in pronouncing a word did not impact recall.
As mentioned previously, the Baddeley and Hitch (1974) model of working memory required greater specificity as to how information was actually processed and stored. The central executive component of the model, in particular, received a great deal of attention and newer theories of working memory revolved around its role and function in the processing and storage of temporary information (i.e. Daneman and Carpenter, 1980, Just and Capenter, 1992). The methods used to measure working memory evolved from simple serial recall measures of words and digits to more complex measures of recall that tapped how individuals process and store information and, likewise, how much information could be stored in working memory. That is, complex span tasks engage the participant in a deeper level of memorial-based cognitive processing.

As outlined by Miyake (2001), span tasks have been helpful to cognitive researchers for three general reasons. First, the processing and storage component of complex span tasks appear to fit the model of working memory developed by Baddeley and colleagues, particularly the hypothesized central executive component. Second, in contrast to simple span measures, complex span measures are more reliable at forecasting higher-order cognition, namely reading comprehension (For an alternative point of view, however, see La Pointe & Engle, 1990). Third, complex span measures have been useful in propagating theories related to higher-level cognition across a wide-array of populations (i.e. healthy and learning-impaired children, college-age students, the elderly and clinical samples).

One of the most frequently used complex span tasks in cognitive research is the Daneman and Carpenter reading span task (1980). The reading span task basically
requires participants to listen to or read sets of sentences and subsequently recall the final word of each sentence in the set. A typical set of sentences may be something like 1) I turned my memories over at random like pictures in a photograph album; 2) He had an odd elongated skull which sat on his shoulder like a pear on a dish; 3) I will not shock my readers with the cold-blooded butchery that followed. Thus, the to-be recalled words are album; dish; followed. In some versions of this test, as participants progress through the test, they read or hear increasingly longer sets of sentences. Because the test creators hypothesized that comprehension is determined by the amount of information that can be retained in working memory, the increasingly longer sets of sentences are thought to tax working memory capacity. Working memory, then, is defined as “the maximum number of sentences the participants could read or listen to while maintaining perfect recall of the final words” (423).

Indeed, by many accounts the reading and listening portions of the Reading Span task predicts reading comprehension performance quite well on both standardized tests of vocabulary knowledge and comprehension (i.e. the Verbal SAT (VSAT) or Nelson-Denny Reading Test) as well as non-standardized language tests (i.e. the ability to make inferences or follow verbal directions) (Daneman & Merikle, 1996). In their original study, Daneman and Carpenter (1980) found an average correlation of .66 with the task and comprehension. Since its creation, there have been countless studies aimed at understanding how (and if) the reading span measures the interaction between memory and higher-level processes (see Daneman & Merikle (1996) for a meta-analysis). Consequently, many new and competing theories have been proposed to explain this interaction. Here we will review four major competing theories.
Daneman, Carpenter, and colleagues (Miyake, Just, & Carpenter, 1994; Just & Carpenter, 1992; Daneman & Carpenter, 1980) proposed a resource sharing theory which posits that the processing and storage components of the memory span rely on a common memory system. As mentioned earlier, this model of working memory focuses more on the central executive component of the Baddeley and Hitch (1974) model of working memory, while removing the modality specific sub stores: the visuospatial sketchpad and phonological loop. According to their view, the efficiency with which an individual completes span measures is contingent upon the amount of cognitive resources available in working memory. For example, readers with good reading skills will likely consume less cognitive resources, enabling them to use additional working memory space to remember the words. Accordingly, these “high-span” individuals would be expected to outperform “low span” individuals with less efficient reading skills on comprehension measures.

Alternatively, others have proposed a processing overlap theory, which stipulates that processing and storage in span measures reflect a multifaceted memory system. Proponents of this perspective, such as Waters and Caplan (1996), argue that the association between working memory and language processing is contingent upon the linguistic function executed. In their view, comprehension may not rely on the same memory system as word-level processing, and vice versa. The Waters and Caplan (1996) reading span task requires participants to read sets of syntactically complex sentences on a computer screen and judge the acceptability of the sentences. Example sentences include, It was the gangsters that broke into the warehouse (acceptable) and It was the pillow that clenched the man (unacceptable). The computer presentation format permits
the researcher to measure reaction time to make the plausibility decision as well as judgment accuracy. After the participants enter their decision an asterisk appears on the computer screen, which alerts participants to recall the last word of each sentence in correct presentation order. Each to-be-recalled word is collectively used as a measure of the participant’s reading span. Waters and Caplan (1996) report that their reading span measure has an internal consistency ranging from .92 to .95.

Still other theorists have focused on the attentional components of working memory measures. Kane, Engle, and Tuholski (2001) have proposed a “controlled attention” view of working memory. According to this perspective, the processing and storage components of span measures reflect an individual’s capacity to actively keep relevant information in memory and discard competing information. Arguably, such processing relies heavily on the central executive component of the working memory model, the system responsible for allocating attentional resources in short-term memory. Given its emphasis on executive-related function, this model then, is inspired by the Just and Carpenter (1992) conceptualization of working memory.

Last, others (e.g. Bryne, 1998; Salthouse, 1996) propose a time-based forgetting theory, which supposes that an individual’s span score is contingent upon how long information can be retained in memory. Proponents of this theory, such as Towse, Hitch, & Hutton (2000) argue that, over the course of completing the span task, an individual’s memorial representation for information decays.

Although researchers are now attempting to resolve these theoretical accounts, the empirical data appears to be mixed with regard to the superiority of one theory against the others. One reason why a resolution has been difficult to reach is because researchers
may be basing their conclusions on different types of tasks and different conceptualizations of working memory or different sub-components of the same model. What we are proposing here is that if, for example, one group of researchers approaches a particular phenomenon from the standpoint of the Baddeley and Hitch conceptualization of working memory, as opposed to say the resource sharing conceptualization of working memory, his or her conclusions will surely not be congruent with the other group of researchers who approach the same phenomenon from the resource sharing theory. Consequently, no consensus can ever be reached on what precisely constitutes a working memory-related issue. Similarly, the tools and methods used to measure a particular phenomenon may only validate or invalidate a theoretical standpoint inasmuch as those tools and methods adequately measure what the phenomenon under study is.

Friedman and Miyake (2004) attempted to resolve two major issues regarding the reading span: (1) if the way in which the test is given to participants affects the validity of the test and (2) how the reading span measures processing efficiency and storage ability. The authors argue that the relationship between a variable of interest, such as reading comprehension, and working memory span score could be small or non-significant because there is, in fact, little relationship between the two; alternatively, the non-significant relationship may also be due to improper administration of the reading span task, such allowing participants more time than necessary to process the sentence. In their study, they compared self-administered against experimenter-administered reading span performance, to see if administration method impacted the criterion validity of the reading span task. By alternating the administration method the authors found that the
extra time taken to implement strategies increased participants’ span scores and, consequently, changed what the reading span task actually measures.

To examine how the reading span measures processing efficiency and storage capacity, they investigated (a) the correlation between processing and storage as measured by the reading span, (b) if sentence position, or increases in sentence length, increases reading span reading times, (c) if the time taken to read practice SAT reading comprehension tests mediates the association between comprehension and reading span performance and (d) if adding processing times to recall increases the predictive power of the reading span. Working memory measures included two parallel forms of the reading span task which included sentences from the original Daneman and Carpenter version as well as sentences from college-level reading material. Subjects’ baseline reading times and time it took participants to read the first to last sentences in a set served as indices of processing speed. Storage ability was measured via two parallel forms of the word span. Finally, comprehension ability was assessed using passages and questions obtained from the SAT reading comprehension tests, as well as subjects’ pre-college test scores on the SAT and ACT.

Their analyses indicated that processing time was associated with storage ability for both administration groups, sentence position increases reading span times, processing time does not mediate the relationship between comprehension and reading span performance, and last, that adding processing times to recall scores only enhanced the predictive power of the reading span for the participant-administered group, but not the experimenter-administered group.
That a relationship was found between processing time and storage ability negates the processing overlap theory because, according to that theory, processing and storage are mutually exclusive. In the experimenter-administered condition, those who had small span scores showed increases in reading time from the first sentence to the last sentence in the set. Participants with higher span scores, conversely, did not have to slow down as much. According to the resource sharing theory, participants who show large increases in reading time from the first to the last sentence in the set do so because the increase in memory load leaves fewer resources for processing. In line with this theory, the results from the study showed a negative correlation between increases in reading time from the first sentence to the last sentence in the set and recall performance. The finding that processing time does not mediate the relationship between comprehension and reading span performance negates all three theories because each hypothesizes some association between processing and storage. The last finding, that adding processing times to recall scores only enhanced the predictive power of the reading span for the participant-administered group but not the experimenter-administered group, fail to support the processing overlap theory because this prediction only proved true for one, but not both, conditions. Consequently, the results of this study bring into question theories about how the reading span task measures processing efficiency and storage ability; particularly the processing overlap theory expounded by the Waters and Caplan research team, and the time-based forgetting theory (Salthouse, 1996, Bryne, 1996).

As evidenced in the preceding pages, the findings from the Friedman and Miyake study may have important implications for studies with aging populations. The reading span task has been widely used among cognitive aging researchers. If, as Friedman and
Miyake demonstrated, administration method may affect the criterion validity of the reading span; this finding could potentially have important implications for theories of cognitive aging. For example, a number of cognitive aging researchers (i.e. Park, 2000, Cherry, Park, Frieske, & Smith, 1996) have argued that more environmentally supportive experimental contexts facilitate performance on cognitive tasks. However, this approach may also limit or constrain the predictive power of the task being administered, as demonstrated by Friedman and Miyake. Moreover, the Friedman and Miyake approach to investigating how the reading span measures processing efficiency and storage ability may help resolve disputes among aging theorists. For example, there is a widely-held belief among cognitive aging theorists that age-related declines in working memory performance are mediated by a decrease in processing speed (Salthouse, 1996). However, as this study demonstrated, decreases in processing speed may not necessarily impact reading span performance, at least for college age participants.

Age, Working Memory, and Simple Span Performance

There is a growing body of evidence which suggests that there are age-related changes in working memory that accompany word span task performance (i.e. Multhaup, et. al, 1996, Kynette, et. al, 1990, Wingfield, Stine, Lahar, & Aberdeen, 1988). Wingfield, et. al. (1988) tested younger and older adults on simple word span task and a "loaded" version of the word span task which, similar to the Daneman and Carpenter (1980) reading span, required participants to listen to a set of sentences, judge the truthfulness of a sentence, and recall the last word of each sentence after all sentences had been presented. Significant age effects were found on both versions of the word span task and were particularly pronounced on the loaded version. A negative correlation was also
found for performance on both types of word span tasks for young and older subjects indicating that performance on the standard word span task was associated with performance on the loaded word span task.

The results of Wingfield, et al. are not surprising given other research which has demonstrated that both young and older adults perform better on the word span than on complex span measures (McCabe and Hartman, 2003). McCabe and Hartman (2003) found that younger and older adults' word span performance also predicted reading span and listening span performance, but the authors also found that this effect did not sufficiently explain the age-related variance in complex span performance. Thus, it still remains unclear what changes in working memory may underlie these differences in word span performance. Here we review the evidence in support of and antithetical to theories of simple working memory span tasks in the context of age-related differences.

Some evidence suggests that age-related differences in word span performance may be due to, as Baddeley suggested, changes associated with phonological capacity. Kynette, Kemper, Norman, and Cheung (1990) measured 82 younger and older adults' performance on a word span task. The results did indicate age-associated differences in word length effects, such that older adults had more difficulty recalling one, two, and three syllable words than younger adults, across conditions. Moreover, they found that articulation rate differed between the two age groups, such that older adults pronounced words more slowly and paused longer between words than younger adults. Thus, given these findings it is possible that changes in the phonological loop may underlie age-related differences in word span task performance.
Other studies, however, suggest that age-related changes in word span performance may be due to other factors, such as the reliance on long-term memory to aid in recall. Multhaup, Balota, and Cowan (1996) measured younger and older adults’ memory for short and long words and non-words. They found that older adults pronounced words more slowly than younger adults for both short and, to a greater extent, longer words. Although the analyses revealed that both younger and older adults recall words better than non-words, older adults appeared to struggle more with non-words than younger adults. At first glance, these results appear to support and extend the findings of Kynette, et. al. (1990). In contrast to the Kynette, et. al. study, however, the younger adults in this study exhibited greater word length effects than older adults. Moreover, that the analyses also indicated that older adults struggle more with longer non-words than shorter non-words and suggests that they may rely on information in long-term memory to delay the decay rate of words in the phonological loop by retrieving lexical representations from long-term storage.

In summary, although there is strong evidence of age-related decline in simple span performance, there seems to be disagreement with regard to what mechanisms underlie these differences. Could these age differences be due to differences in working memory capacity or are they more indicative of the role of long-term memory in span performance?

Age, Working Memory and Complex Span Performance

Not surprisingly, complex span measures are widely used among researchers interested in individual difference variables, particularly those interested in age-related changes in cognition. For this group of researchers, the reading span is believed to be a
reliable indicator of age-related changes in reading comprehension, episodic memory, and fluid cognition (Zacks, Hasher, & Li, 2000).

Over the last several years, researchers have been examining the relationship between working memory span and children's comprehension abilities. In one well-known study, Towse, Hitch, & Hutton (1998) administered a slightly modified version of the reading span task to children, ages 8 to 10 years old. Task sentences had, of course, been adjusted to contain age-appropriate material (i.e. the magician waved his magic wand), as opposed to the standard, college reading level sentences. Their analyses indicated a strong association between age and reading speed. Interestingly, however, they failed to find any evidence for improvement in reading span with age; however, similar to adult studies, they did discover that the longer a subject was required to retain task information in memory (final words), the poorer the participant's performance was.

On the other end of the age spectrum, studies in the cognitive aging literature have demonstrated that working memory capacity declines with age (Park et. al, 1996, Salthouse & Babcock, 1991). According to a meta-analysis, the average older adult working memory span falls at the 21st percentile of the distribution of complex span scores among all adults (Verhaeghen, Marcoen, & Goossens, 1993). Thus, there is some evidence suggesting that older adults may rely on a common working memory resource when completing complex span measures, such as the reading span task.

It has been argued that, despite the consistent finding of age-related decrements in working memory capacity, there may be other factors that confound the working memory measure. For example, vocabulary commonly covaries with working memory span performance for older adults. That is, older adults with vocabularies higher than the
college-age comparative group may have a special advantage on complex span tasks which might yield unreliable scores. McCabe and Hartman (2003), for example, found that vocabulary was a significant covariate of age and complex span performance.

Likewise, previous studies of older adults' processing of syntactically complex sentences have been correlated with working memory span (MacDonald et. al., 1992). However, recent structural equation modeling has demonstrated that associations between age, working memory, and language processing may be contingent upon what facet of language processing is measured or the working memory task that is used. DeDe, Caplan, Kemtes, and Waters (2004) found that the impact of aging on working memory performance varies by experimental condition (i.e. offline comprehension v. online comprehension). The authors' results also suggest that, in contrast to the findings of Kane, et. al. (2004), online measures of verbal working memory do not tap modality specific working memory resources. Consequently, there is no agreed upon theoretical explanation for age-related differences in complex span performance.

It is possible that contextual features of task administration may also contribute to age-related differences in sentence span performance. For example, time-limits may impose further processing demands on performance for older adults. Glick, Craik, & Morris (1988, also see Craik, Morris, & Glick (1990)) presented younger and older participants with a modified version of the Daneman and Carpenter (1980) sentence span task in which subjects read a set of sentences, judged if the statement was true or false, and, finally, recalled the final word of the sentences under both paced and unpaced conditions. Although the analyses indicated that time constraints in the paced condition did cause subjects to increase their response latencies and commit more recall errors, the
effect was not differentially affected by age. That is, removing time constraints did not improve or hamper older adults’ performance on the sentence span task.

Other studies, however, have demonstrated that time constraints may differentially impact older adults’ performance. Brebion (2003) sought to determine if slower reading times among older participants were due to differences in memory strategy or speed of processing. To do this, he manipulated the task instructions, such that participants were instructed to either answer as quickly and accurately as possible or to simply answer as fast as possible, without regard for accuracy. This approach revealed the following: When instructed to respond as quickly and accurately as possible, older participants scored higher than younger participants. When instructed to respond as quickly as possible, there appeared to be no significant age differences. These results suggest that, perhaps, older adults use a different (or more cautious) processing strategy than younger adults on reading span measures. What those strategies may be still remains a mystery.

Three major hypotheses have been proposed to explain age-related differences in reading span scores: (1) reduction in working memory capacity (Baddeley, 1986), (2) the inhibition deficit theory (Hasher and Zacks, 1988), and (3) the slowing hypothesis (Salthouse, 1996).

Regarding the first of these, although the reading span does not directly measure Baddeley’s proposed tripartite model of working memory (a central executive control with two component subsystems: the phonological loop and visuospatial sketchpad), it is presumed to capture the essential processing and storage elements of the central executive. There is some recent evidence which suggests that age-associated decline on the reading span task may be due to declines in the phonological loop and central

The second theory, Hasher and Zacks (1988) inhibition deficit theory, posits that age-related changes in working memory prevent older adults from inhibiting irrelevant or off-task information. Hypothesizing that performance on the reading span task may be affected by the older adult users’ inability to suppress irrelevant information, May, Hasher, and Kane (1999) conducted a two-part experiment in which college-age and healthy older adults were administered two different versions of the span task: the standard version, in which sentence sets increase in difficulty, and an alternative version which began with more complex material and gradually became easier. The idea behind this manipulation was that presenting subjects with larger sets first would minimize the role of interference on successive trials. As expected, older adults who completed the standard version of the reading span task performed poorer than the younger adults. The older adults who completed the alternate version, however, performed comparatively with the younger adults. The mean score for older adults on the alternative version was 3.0 (sd=.4) and the mean score for younger adults was 2.9 (sd=.05).

Support for the inhibition-deficit hypothesis has been mixed and controversial (McCabe & Hartman, 2003, Schelstraete & Hupet, 2002, Burke, 1997). Schelstraete and Hupet (2002) investigated the inhibition-deficit theory in French-speaking older adults’ reading span performance. Participants were presented sentences on white cards and the total number of correctly recalled target words counted as their span. If the participant recalled words from previous lists, instead of target list, their responses were coded as an interference response. Inhibition was measured using the Stroop Color-Word task.
Although the authors did find age-related decline in span performance and ability to resist intruding responses, they failed to identify any correlation between span performance and Stroop task performance. Based on these results, the authors concluded that some factor other than the decline in inhibition, such as general slowing or specific working memory impairment, must be responsible for age-effects on span performance.

Salthouse (1996) hypothesized that age-related changes in memory and language abilities are due to declines in the speed of mental processing. The speed of processing theory is based on two major assumptions, the first of which stipulates that constraints on general processing, knowledge, and the efficiency of specific cognitive processes limit performance on cognitive tasks (although these constraints may be overcome with expertise or experience) (Salthouse, 2001). The second assumption of the speed of processing theory is that, with age, age-associated slowing inhibits performance on cognitive tasks. Salthouse (2000) reports five different major variables that have been employed to assess speed of processing: decision speed, perceptual speed, psychomotor speed, reaction time, and time course of internal responses. Of these five variables, the one most commonly used to assess speed of processing in cognitive-aging studies is reaction time. This construct is typically measured by recording the amount of time it takes participants to press a key during presentation of stimuli.

Previous research also indicates statistically significant correlations between measures of processing speed (i.e. the Weschler Digit Symbol Comparison test) and working memory tasks (Salthouse, 2001). Incorporating these measures into cognitive aging experiments has been particularly fruitful in examining age-related declines in working memory performance and isolating the cause and effect relationship between
processing speed and span performance. In a classic study conducted by Salthouse and Babcock (1991) it was found that younger and older adults' performance on two complex working memory measures (the operation span and listening span) were highly correlated with measures of processing speed (see diagram below).

Figure 2. Path diagram from study 2 of Salthouse & Babcock (1991).

There is some evidence which suggests that theories of cognitive aging may not be independent or exclusive of one another. Van der Linden and colleagues (1999), for example, argue that general slowing and the inability to inhibit competing information may be reflective of age-related declines in working memory. Others have argued that, based on data obtained from longitudinal studies, overall age-related changes in the brain may be responsible for differences in the cognitive performance of older adults and younger adults. "The Common Cause" Hypothesis, proposed by Baltes & Lindenberger (1997), maintains that both perceptual and cognitive decline reflect either widespread
degeneration in the central nervous system or changes in specific functions or circuitry that have system-wide consequences.

Although researchers are presently attempting to resolve these theoretical accounts, the empirical data appears to be mixed with regard to the superiority of one theory against the others. Recently, McCabe and Hartman (2003) attempted to resolve some of the differing theoretical accounts of age-related differences on span performance by comparing young and old adults’ performance on simple (word span, dual-task word span), working memory tasks and complex (reading span, listening span) working memory tasks, and language and lower level processing speed tasks (Pattern Comparison, Letter Comparison) and fitting the results with the major theories.

To determine if age-related decline on span performance is mitigated by reduced working memory capacity, the authors compared performance on both single and dual-task versions of the word span, with the expectation that older adults would exhibit more difficulty in completing the dual-task word span as compared with the single task version because of difficulty in processing concurrent information due to reduced central executive function. Although younger adults outperformed older adults on the word span task, when comparing each participant’s score at the word-span-minus-one level (with final word recall as the dependent variable) no significant age differences were identified for performance on either version of the task and, consequently, no evidence was found in support of the storage-deficit hypothesis.

Inhibition deficit was measured by comparing (1) the proportion of errors incurred on the reading span and listening span tasks and (2) the proportion of errors incurred on the listening span and dual-task word span tasks. The first set of analyses indicated non-
significant results. The second set of analyses, comparing age-related scores on the listening span task and dual-task word span task, indicated no significant age differences on either task. Thus, no support was found for the inhibition-deficit hypothesis of age-related differences on span performance.

McCabe and Hartman also investigated if age-related variance on complex span tasks could be explained by older adults’ weakness at comprehending syntactically difficult sentences. Reasoning that older adults would exhibit more difficulty on the reading span task, which required the participants to read sets of sentences, versus the listening span task, which requires participants to hear sets of sentences, the authors expected that older adults would exhibit more difficulty reading sentences due to increased difficulties in comprehending syntactic material. Contrary to their expectations, analyses indicated no significant age differences on reading or listening span performance.

Although the results provide compelling evidence in favor of the speed-of-processing theory, it may be said that they fail to completely resolve the different theories on age-related differences in complex span performance. One problem with this study was that the authors failed to adequately test the reduced capacity hypothesis. That is, there is no measure of articulatory duration or word-length effect, rendering their results rather dubious. Another problem with the McCabe and Hartman study is that it fails to account for potential age-related differences in strategy use for complex span (i.e. rehearsal). Last, the authors insufficiently measured the syntactic processing argument. Simply comparing reading of sentences to the listening of sentences does not syntactic processing measure make, it only measures if there are age differences in the reading of typical sentences.
The authors might have considered, for example, presenting the participants with syntactically complex or ambiguous sentences.
CHAPTER 3

METHODOLOGY

The Present Study

The study has three specific aims. The first specific aim of this study is to assess the effect of administration method on the criterion validity of two commonly used working memory span measures, the Daneman and Carpenter reading span and the Waters and Caplan sentence span, on college-age and healthy older adults. This goal may be accomplished by comparing subjects’ performance on self-administered and experimenter administered testing procedures. The second specific aim of this study is to investigate how reading span tasks measure processing and storage of verbal information in college-age and healthy older adults. The third specific aim of this study is to examine what cognitive processing strategies participants use on the word span task. In order to achieve the last goal of the study, analyses will include a comparison of participants’ reported strategies with measures of sub-vocal rehearsal.

Subjects

A total of 84 individuals participated in the study (42 college-age adults, 42 older adults). Younger subjects had an average age of 20.07 ($SD = 1.91$) years and older subjects had an average age of 74.47 (4.82) years. In the present sample 57% of the participants were female and 43% were male. Younger participants averaged 13.9 ($SD =
1.2) years of education and the older adults averaged 15.80 (SD = 2.9) years of education. Educational backgrounds were significantly different among the young and older participants, t (33) = -2.05, p < .05.

The college-age participants were recruited from the university psychology subject pool and were awarded class credit for their participation. The older adults were recruited from flyers posted in community centers and received a stipend of $20 for their participation in the study.

Procedure and Materials

The experiment took place on the university campus over two testing sessions. Both testing session were held approximately one week apart (M=8.95 days, SD= 4). The first testing session lasted an average of 108 minutes for the younger participants and 114 minutes for the older adults. The second testing session lasted an average 104 minutes for the younger participants and 84 minutes for the older adults.

The first testing session began with the administration of the screening measures (detailed below), followed by the baseline reading measure, backwards digit span, and either the self-paced or timed working memory span tasks. Span task administration order was randomized. In the second testing session, subjects completed either the self-paced or timed working memory measures and the reading comprehension measure (described below).

Computerized experimental tasks were administered on a Macintosh personal computing system (www.apple.com), and programmed using PsyScope 1.2.5 (http://psyscope.psy.cmu.edu/psyscope).
All subjects were tested on a battery of neuropsychological measures to rule out any signs of cognitive decline or dementia. The background measures included the Mini-Mental State Exam (MMSE for all subjects, Folstein, Folstein, & McHugh, 1975), the Logical Memory I and II subtests of the Wechsler Memory Scale-Revised (WMS-R, Wechsler, 1987), and the 15-item abbreviated Boston Naming Test\(^1\) (BNT; Goodglass & Kaplan, 1972).

**Language Measures**

**WAIS Battery Vocabulary** This verbal subtest of the Wechsler Adult Intelligence Scale (Wechsler, 1987) is a general measure of an individual's vocabulary knowledge. The test is comprised of three practice items and thirty main items. The experimenter read each word to the participant, and the participant responded with their best definition of each word. Scoring of the vocabulary test is based on a three-point criterion system.

**Nelson-Denny Reading Comprehension** Participants' reading comprehension was assessed using the Nelson-Denny Reading Test Form E (Brown, Bennett, & Hanna, 1981). The test consists of eight reading passages each followed by four multiple choice comprehension questions, each with five answer choices \((a,b,c,d,\) or \(e)\). Topics range from science to the arts. Participants are allowed twenty minutes to read as many passages and answer as many question sets as they are capable of answering. The Nelson-Denny reading comprehension test was designed to be administered in a “paper-pencil” format, such that participants read the passages and answer the comprehension questions in a unitary test booklet. In the present experiment, however, task stimuli were digitally scanned from the original task cards and presented to the participants on a computer monitor.\(^1\)

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\(^{1}\)**The BNT is typically administered using spiral-bound index cards. Each card is individually presented to the participant, and the participant says the name of the item out-loud. In the present experiment, however, task stimuli were digitally scanned from the original task cards and presented to the participants on a computer monitor.**
the reading passages and question sets were administered electronically on a personal computing system. Passages and questions appeared in white, 14 pt. Times New Roman font against a solid black background. Participants read each passage silently and after reading the passage, pressed the space bar on the keyboard to activate the multiple choice comprehension questions. Each comprehension question appeared individually below the reading passage and participants entered their answer choices by selecting the correct answer from a specially labeled set of keys on the keyboard. Once a response was entered, the next question appeared in place of the previous question. Responses and reading times were discretely recorded by the testing software for subsequent analysis. Each correct response was valued at two points.

Due to space constraints on the testing apparatus, one of the eight original reading passages was omitted from the computerized version of the reading comprehension measure, leaving the final number of passages to seven.

Processing Speed

Symbol-Symbol and Digit-Symbol Task Processing speed was assessed using a computerized version of the Wechsler Adult Intelligence Scale digit symbol (Weschler, 1987) and the symbol-symbol tasks. Each task consisted of ten practice trials and ninety test items. In the symbol-symbol task, participants were presented with a pair of symbols on the computer screen. The participant's task was to determine if the symbol pairs matched or did not match. Decisions were entered by pressing either "yes" or "no" buttons on the computer keyboard. In the digit-symbol task participants observed a table of matched digits and symbols at the top of the computer screen and a digit-symbol pair below in the center of the screen. Participants were instructed to decide whether the digit-
symbol pairs matched or did not match the digit-symbol pairs in the table. Similar to the symbol-symbol task, decisions were entered by pressing either “yes” or “no” buttons on the keyboard. Scoring consisted of awarding one point for each correctly entered response.

Baseline Reading Task The baseline reading task (BRT) required participant to simply read thirty-seven unique sentences out-loud at their normal reading pace. Task stimuli included unused sentences from both the Daneman & Carpenter reading span task and Waters and Caplan sentence span tasks (described below). To be sure, none of the BRT sentences appeared in any other measure in the experiment. Each sentence appeared one at a time—in randomized presentation order—on a personal computer monitor in white, 24 pt. Arial font against a black background. After the participant had finished reading each sentence, they were instructed to press the space bar on the keyboard to advance to the next sentence. They would repeat this process until all thirty-seven sentences had been read and the computer instructed them to stop. The amount of time that lapsed between the initial presentation of the sentence and the time taken for the participant to advance to the following sentences represented the participants reading time. The reading times recorded by the computer were included in the final data analysis.

Working Memory Measures

Backwards Digit Span task The backwards digit span task requires participants to silently view lists of random digits and to verbally recall each digit in reverse order. The task consists of seventy random digits arranged in eight groups. Digits are presented individually, beginning with two digits. The number of presented digits increased with
each succeeding group. Participants were tested on two trials at each level. The task consists of three scoring criteria: (1) a raw score, which is the total points acquired across all groups and trials, (2) a sub-score of the greatest number of recalled items where at least one trial was passed, and (3) a second sub-score of the greatest number of recalled items where both trials were passed. Scores presented in the present set of data represent the average number of span levels (2 trials) achieved. Task stimuli were presented on a computer screen. Each digit series was presented in white, 36 pt. Arial font against a black background.

**Word Span Task** The word span task required participants to silently read lists of random words and subsequently recall as many of the words as they could in serial order. Two parallel forms of the word span task were used. Each version was counter-balanced across sessions to avoid practice effects. The task contained 132 one and three syllable nouns (sixty-six one syllable nouns and sixty-six three syllable nouns). Task stimuli were obtained from the online Kucera and Francis (1986) database from the University of Western Australia MRC Psycholinguistic database. Words were selected based on their properties (nouns), frequency, and syllable length (one, three). The target word span words were different than the target words in the other span task measures.

Each of the words was divided among six spans. Each span was divided into three trials. With each successive span, the number of trials increased from two to six words, but span presentation order was randomized to prevent learning or interference effects. After completing each span, the participant was prompted to advance to the next span (i.e. “go on to level 2?”). This message appeared in 36 pt red Arial font, to distinguish it from the task-related stimuli. All participants completed each of the six spans.
Daneman and Carpenter Reading Span Task

The Daneman and Carpenter reading span task (Daneman & Carpenter, 1980) requires participants to read sets of sentences out-loud and to recall the last word of each sentence in serial order. An example sentence might be *Otto has been working very hard but he has finished at last*. In this example, the target word would be *last*. The task contained sixty-six sentences, including six practice sentences. Two parallel forms of the reading span task were constructed. Each version was counter-balanced across sessions to deter practice effects.

Task stimuli were divided into six randomized spans. Each span was composed of three trials followed by a recall period. The number of to-be-recalled stimuli increased with each successive span. Thus, in span two the participant recalled three sets of two words, for a total of six words. In span three, the participant recalled three sets of three words, for a total of nine words, and so on.

Daneman and Carpenter (1980) presented the reading span task stimuli on note cards to their participants. In the present experiment, however, task stimuli were presented visually to the participants on a personal computer. The decision to present the task on a personal computer was based on the fact that, in the self-paced condition, the computer would permit discrete recording of the participants' reaction times to read each sentence. More specifically, for the self-paced condition, the participants would advance to the next sentence by pressing the spacebar on the keyboard after they finished reading the present sentence. As with the BRT, the amount of time that lapsed between the initial presentation of the sentence and the time taken for the participant to advance to the following sentences represented the participant's reading time. The reading times recorded by the computer were included in the final data analysis. The second reason for
the decision to use computer-based presentation of the reading span task was that computer presentation permitted accurate timed presentation of task material. In the timed condition participants viewed each sentence for a maximum of 6000 ms before the computer would automatically advance to the next sentence. The recall period was signaled by the appearance of a white asterisk on the computer monitor.

In both the self-paced and timed conditions, each sentence appeared in white, 36 pt. Arial font against a black background. After completing each span, the participant was prompted to advance to the next span (i.e. "go on to level 2?"). This message appeared in 36 pt. red Arial font, to distinguish it from the task-related stimuli. All participants completed each of the six spans.

A participant's working memory span was the highest span level achieved in which two of three trials were perfectly recalled. An additional .5 was added to a participant’s score if he/she demonstrated perfect recall for one of the three trials in the following span size.

Waters and Caplan Sentence Span Task The Waters and Caplan sentence span task (Waters & Caplan, 1996) requires participants to silently read sets of syntactically normal and complex sentences, decide whether each sentence makes sense, and recall the last word of each sentence at a designated recall period. An example of an acceptable sentence might be *It was the gangsters that broke into the warehouse*. An example of an unacceptable sentence might be *It was the housewife that angered the cigarette butts*. In this example the target words would be *warehouse* and *butts*. The traditional sentence span task consists of 200 acceptable and 200 unacceptable sentences divided among four different sentence types (cleft subject, cleft object, object-subject, and subject-object).
the present experiment, however, only sixty-six cleft subject (CS) sentences were used, six of which were practice items. Half of the sentences were acceptable and half of the sentences were unacceptable. Similar to the reading span task, all sentence material was divided into six span levels, with three trial sets per level. Span presentation order was randomized to prevent learning or interference effects.

In contrast to the reading span task, the sentence span task has always been an electronically-administered task, and so it was in the present experiment. Sentence stimuli were presented in 36 pt. white Arial font against a black background. Participants were instructed to read each sentence silently and to immediately decide whether or not the sentence made sense. Participants entered their responses on the keyboard by manually pressing specially labeled “yes” and “no” keys. After a response was entered, the computer would advance to the next sentence or to the recall asterisk at the designated time. In the timed version of the sentence span task, the task stimuli would briefly appear on the monitor for a total of 6000 ms before it would disappear and the screen would become blank. Acceptability judgments could only be entered once the sentence disappeared from the computer screen and not sooner.

**Strategy Interviews**

Working memory span task strategy interviews were conducted for both self-paced and timed administrations of the word, reading, and sentences span tasks. Upon completion of each task participants were asked how they remembered the to-be-recalled task words, if they used any special techniques to remember the words, how frequently they used the technique to remember the words, and if there was anything else they could report about how they remembered the words. Each participant’s responses were audio-
recorded during the testing session for accuracy and subsequently transcribed for analysis.

At the end of each testing session, participants also completed a brief strategy survey. Before completing the survey, participants were instructed to reflect back on each of the tasks they had completed during the testing sessions that required them to remember words. The survey consisted of three multiple-choice questions. The first asked if they had used any special techniques to help them remember the words. Participants either circled “yes” or “no”. The second question asked the participants to select from a list of options which of the choices most strongly described how they remembered the words. Choices included: (1) making a sentence with the words, (2) picturing the words (3) repeating the words, (4) putting the words together, or (5) an “other” option. If the participant chose the other option, a space was provided so that the participant could describe what they did to help them remember the words. Responses were double-checked by the experimenter, so that if the participant mistakenly selected more than one option from the choice arrays, they were asked to choose the one that most strongly described what they did during the experiment. If they could not choose one of the options, then the participant was encouraged to select the “other” option. Last, participants were asked how often they used the technique to help them remember the word. Choice options were: (1) I did not use a technique, (2) some of the time, (3) most of the time, or (4) all of the time.

The post-experiment survey served two purposes. First, the survey provided additional information about a participant’s memory strategies. Obviously, this would be especially useful if the audio recording of the strategy interview were lost or damaged.
Second, the post-experiment survey served as a quasi-reliability indicator, to the degree that participants’ interviews could be compared with the self-reported strategy survey data. An argument could be made that the survey might have suggested to the participant potential strategy techniques, but for precisely this reason, the survey was not administered until the conclusion of each testing session. Since each testing session was generally one week apart this, too, was believed to have minimized the risk of inadvertently suggesting any technique to the participant.
CHAPTER 4

FINDINGS OF THE STUDY

Results

Background Screening Measures

The present experiment included three neuropsychological screening measures, including parts I and II of the Logical Memory (LM; Wechsler Memory Scale, Wechsler & Stone, 1945), an abbreviated fifteen-item version of the Boston Naming Test (BNT; Goodglass & Kaplan, 1972), Mini-Mental State Exam (MMSE for all subjects, Folstein, Folstein, & McHugh, 1975). All means and standard deviations for the background screening measures are reported in Table 1. Multivariate analysis of variance (MANOVA) was conducted on background measure scores. There was a statistically significant main effect for age, $F(7, 73) = 3.32, p < .004$, partial $\eta^2 = .24$. Planned comparisons of young and older adults’ means on the individual measures (corrected using a Bonferroni adjustment indicated significant differences between the two age groups for the BNT, $F(1, 79) = 6.94, p < .01$, partial $\eta^2 = .08$, as well as nearly significant differences between the two age groups for the LM I thematic, $F(1, 79) = 3.69, p < .058$, and LM II recall, $F(1, 79) = 3.68, p < .059$, scores.
Language Ability

Language ability, as measured by the WAIS vocabulary subtest, was calculated for each participant as the maximum points earned. A paired samples T-test revealed that older adults’ vocabulary scores ($M=50.53$, $SD=8.46$) were superior to young adults’ vocabulary scores ($M=41.3$, $SD=8.12$); $t(39) = -4.80$, $p<.000$.

Processing Speed

Processing speed, as measured by the symbol-symbol and digit-symbol comparison tasks, was calculated by dividing participants mean reaction time by the number of correct responses and multiplying the product by 1000. Using this formula, the older adults had higher symbol-symbol scores ($M = .0147$, $SD = .0143$) as compared with the younger adults ($M = .0092$, $SD = .0019$), $t(41) = -2.45$, $p < .02$. For the digit-symbol measures, the older adults also had high scores ($M = .0222$, $SD = .0047$) as compared with the younger adults ($M = .0154$, $SD = .0032$), $t(41) = -7.97$, $p < .00$.

Baseline Reading

Baseline reading was measured as the average reading time (in msec) for a set of 37 unused sentences from the reading and sentence span tasks. A univariate ANOVA revealed that younger adults’ mean reading times ($M = 5924.42$, $SD = 1032.20$) were shorter than the older adults’ mean reading times ($M = 6841.10$, $SD = 1344.30$); $F(1, 82) = 12.29$, $p > .001$
Table 1  Mean Scores for all Experimental Measures

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<td>36.51</td>
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<tr>
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<tr>
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<td>.0147</td>
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<td>1.3</td>
<td>1.79</td>
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<td>3.9</td>
<td>.79</td>
<td>3.42**</td>
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Note: LMI_RTS= Logical Memory I recall total score, LMI_TTS= Logical Memory I thematic total score, LMI_RTS= Logical Memory II recall total score, LMI_TTS= Logical Memory II thematic total score, LMI_REC= Logical Memory II recognition total score, MMSE= mini-mental state examination, VCAB= WAIS VCAB= vocabulary score, BNT= Boston Naming Test, SYM-SYM= Symbol-Symbol Comparison, DIG-SYM= Digit-Symbol Comparison, BD_SPAN= Backwards Digit Span, W_SPAN1= self-paced one-syllable word span, W_SPAN3= self-paced 3 syllable word span, R_SPAN= self-paced reading span, S_SPAN= self-paced sentence span, TW_SPAN1= timed one-syllable word span, TW_SPAN3= timed 3-syllable word span, TR_SPAN= timed reading span, TS_SPAN= timed sentence span, W_SPANCOMP= self-paced word span composite score, TW_SPANCOMP= timed word span composite score, WM_COMP= working memory composite score, TWM_COMP= timed working memory composite score, ND_SSCORE= Nelson-Denny standard score, ND_RSCORE= Nelson-Denny ratio score.

*p ≤ .05; ** p ≤ .01; *** p ≤ .0001
Short term memory span

There were three measures of short-term memory in the present study: backwards digit span, one-syllable, and three-syllable word span. The word span tasks were administered under self-paced and timed conditions, the backwards digit span was not. There was no statistically significant difference between the two age groups with regard to backwards digit span scores, $F(1, 83) = 2.18, p > .14$. This finding is not unusual in the cognitive aging domain (see Bopp & Vergaeghen’s (2005) meta-analysis for an extended discussion on the topic).

Data collected from the word span measures were analyzed in a 2 (age group) x 2 (presentation format) x 2 (span task) repeated measures ANOVA. Although the 3 way interaction between presentation format, span task, and age group was not significant ($F(1, 82) = .18, p > .68, ns.$), several of the lower-order comparisons were. Younger adults’ scores were overall higher across tasks compared to older adults’ scores which resulted in a main effect of age, $F(1, 82) = 12.79, p < .001$, partial $\eta^2 = .14$. Scores for the one-syllable word span task were significantly higher than scores for the three-syllable word span task which resulted in a main effect of span task, $F(1, 82) = 58.29, p < .005$, partial $\eta^2 = .42$. Participants’ scores were significantly higher for the self-paced compared to timed condition, $F(1, 82) = 15.75, p < .005$, partial $\eta^2 = .16$. However, interactions between span task and presentation format, $F(1, 82) = .033, p > .86, ns$, age and span task, $F(1, 82) = .06, p > .80, ns$, and age and presentation format, $F(1, 82) = 1.92, p > .17, ns$, were not significant.

Paired t-test results (Figure 3) indicated that word length (and to a lesser degree, administration condition) contributed to one- and three-syllable word span performance.
There were significant differences between both young and older adults' recall of self-paced one- and three-syllable words, self-paced and timed three-syllable words, and timed one- and three-syllable words. Younger adults, but not older adults, exhibited significant differences in their recall of self-paced and timed one-syllable words. Between age-group differences were found for young and older adults' recall self-paced one- and three-syllable words, as well as timed three-syllable words.

**Working memory span**

The present study included two measures of working memory span, the Daneman and Carpenter reading span and the Waters and Caplan sentence span, which were both administered under self-paced and timed conditions. Working memory span was defined as the largest span achieved in which two out of the three trials were perfectly recalled. An additional .5 was added to the participants span score if the next trial was also perfectly recalled. Mean span scores and T-values are available from table 1.

Following the conventions of Waters and Caplan (1996), a composite Z-score was calculated for each participant's sentence span scores. The composite score was used for all subsequent analyses.

A 2 (age group) x 2 (presentation format) x 2 (span task) repeated measures ANOVA was conducted on span task scores.

Although the 3-way interaction between presentation format, span task, and age group was not significant, $F(1, 82) = .20, p > .66$, several of the lower-order comparisons were. For both age groups, participants' scores were significantly higher for the reading span task compared to the sentence span task resulting in a main effect of span task, $F(1, 82) = 721.92, p < .00$, partial $\eta^2 = .90$. Younger adults' scores were overall higher across
tasks compared to older adults’ scores which resulted in a marginally significant main effect of age, $F(1, 82) = 3.51, p < .06$, partial $\eta^2 = .04$. However, the interaction between presentation format and age, $F(1, 82) = .28, p > .60$, was not significant.

Paired T-tests indicated significant within-group differences between the younger adults self-paced reading and sentence span scores, $t(41) = 15.68, p < .01$, and timed reading and sentence span scores, $t(41) = 21.32, p < .01$, as well as older adults’ self-paced and timed reading and sentence span scores, respectively $t(41) = 15.46, p < .01$ and $t(41) = 16.86, p < .01$. However, there were no significant differences between the younger adults’ self-paced and timed reading span scores, all $p$’s > .05, or the older adults self-paced and timed reading span scores, all $p$’s > .05; nor were there any significant differences between the young adults’ self-paced and timed sentence span scores, $p > .05$, or the older adults’ self-paced and timed sentence span scores, $p > .05$. No significant between-group differences were identified, all $p$’s > .05.

Collectively, these results suggest that increased task demands (reading + judging the sentence acceptability + final word recall) contribute more to the age-related variance in verbal working memory span task performance than administration procedure.
Figure 3. Mean working memory spans (+ SE) for self-paced and timed administration conditions.
Figure 4. Paired t-test comparisons for simple and complex memory span tasks.
Separate analyses of covariance (ANCOVA) were conducted to test the prediction that WAIS vocabulary scores would be a significant covariate of span task scores. Data collected from the word span measures were analyzed in a 2 (age group) x 2 (presentation format) x 2 (span task) repeated measures ANCOVA with vocabulary as the covariate. Although the 3-way interaction with the covariate was not significant, the older adults’ superior vocabulary scores yielded a significant between-subjects main effect for vocabulary, $F(1, 79) = 27.15, MSE = 25.31, p < .00, \eta^2 = .13$. None of the other effects were significant, all $p$'s > .05.

Data collected from the working memory measures were analyzed in a 2 (age group) x 2 (presentation format) x 2 (span task) repeated measures ANCOVA with vocabulary as the covariate. The 3-way interaction between presentation format, span task, and vocabulary was significant, $F(1, 79) = 8.06, MSE = 9.00, p < .01, \eta^2 = .09$. The 2-way interaction between vocabulary and span task was also significant, $F(1, 79) = 34.40, MSE = 27.65, p < .00, \eta^2 = .30$.

To investigate the possibility of multicolinearity effects, Pearson-Product moment correlations were computed for the WAIS-R vocabulary and the span task scores. Three-syllable word span correlated strongly with young and older participants’ vocabulary scores. In general, the association between span task performance and vocabulary tended to be higher for the older adults—with the exceptions of self-paced three-syllable word span, which was higher for the younger subjects, $r = .45, p < .01$ vs. $r = .38, p < .05$, and self-paced sentence span, which was nearly equivalent between the two groups, $r = -.68$, etc.
p < .01 (young) and r = -.66, p < .01 (old). Tests of all young-old correlations failed to reach significance, all p's > .05.

Table 2  Product-Moment Correlations for WAIS-R Vocabulary Scores and Span Task Scores.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Young Self-paced</th>
<th>Young Timed</th>
<th>Old Self-paced</th>
<th>Old Timed</th>
</tr>
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<td>.42**</td>
<td>.29</td>
<td>.49**</td>
</tr>
<tr>
<td>3 syllable Word Span</td>
<td>.45**</td>
<td>.31*</td>
<td>.38*</td>
<td>.59**</td>
</tr>
<tr>
<td>Reading Span</td>
<td>.24</td>
<td>.33*</td>
<td>.55**</td>
<td>.42**</td>
</tr>
<tr>
<td>Sentence Span</td>
<td>-.68**</td>
<td>-.25</td>
<td>-.66**</td>
<td>-.38*</td>
</tr>
</tbody>
</table>

* = p < .05, ** = p < .01

One interesting pattern of note is the correlations between older adults' vocabulary and span scores appears to change as a function of task demands and administration condition. That is, the correlation between vocabulary and timed word span is higher than the correlation between vocabulary and self-paced word span. On the other hand, the correlation between vocabulary and working memory is higher for the self-paced spans and lower for the timed spans.

Correlations

Pearson-product correlations were computed for young and older adults' memory span scores. An examination of the inter-measure correlations for the younger adults reveals a few interesting patterns. The correlation between one- and three- syllable word span was fairly consistent under both self-paced (r = .44, p < .01) and timed (r = .46, p < .01).
administration conditions; as were the correlations between self-paced and timed reading and sentence span, \( r = -0.43 \) and \( r = 0.43 \), (all \( p's < 0.01 \)) respectively. The relationship between word span and working memory span was generally stronger for the three-syllable word span under self-paced administration conditions and one-syllable word span under timed conditions.

As with the younger adults’ scores, the older adults’ span scores (table 5) evidences a fairly consistent pattern of bivariate correlations between self-paced and timed administrations of both word and working memory spans. Neither time nor task demands appeared to have any effect on the relationships within the measures. In contrast to the observed pattern of correlations with younger adults, however, three-syllable word span scores correlated more strongly with both measures of working memory under both self-paced and timed administration.

Could the effects of normal aging contribute to the observed differences in the present pattern of correlations? An examination of the young and old correlation matrices reveals a few interesting patterns. The correlations between one- and three-syllable word span was higher for the older adults, as compared with the younger adults, for both the self-paced \( (r = 0.58 \text{ vs. } r = 0.44) \) and timed \( (r = 0.61 \text{ vs. } r = 0.46) \) administration conditions. However, a test of these independent correlations failed to reach significance, respectively \( z = 0.84, p = 0.40 \) and \( z = 0.93, p = 0.35 \). The correlations between reading and sentence span were also higher for the older adults for both the self-paced \( (r = -0.46 \text{ vs. } r = -0.43) \) and timed \( (r = -0.48 \text{ vs. } r = -0.43) \) administration conditions. Yet a test of these correlations also failed to reach statistical significance, respectively \( z = 0.17, p = 0.87 \), and \( z = 0.28, p = 0.78 \).
In sum, the administration condition had little effect on the relationship between one and three-syllable word span, nor did it exhibit any effect on the relationship between reading and sentence span. Second, the cognitive effects of aging did not contribute in any meaningful way to the inter-measure relationships between one- and three syllable word spans, nor did it contribute to the relationship between reading and sentence span—despite an overall stronger pattern of observed within-measure correlations for the older adults. Third, the pattern of between-measures correlations indicates that three-syllable word span exhibits a moderately stronger relationship with the traditional measures of verbal working memory span, as compared with one-syllable word span, regardless of age. Taken collectively, the differences in the patterns of correlations between the different classes of measures are likely due more to time constraints in the span task administration, than the contributions of normal aging.

Table 3: Product-Moment Correlations for Young Adults Working Memory Spans

<table>
<thead>
<tr>
<th>Measure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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</table>

Note. BDS= backwards digit span, SP_WS1= self-paced one-syllable word span, SP_WS3= self-paced three-syllable word span, SP_RS= self-paced reading span, SP_SS= self-paced sentence span, T_WS1= timed one-syllable word span, T_WS3= timed three-syllable word span, T_RS= timed reading span, T_SS= timed sentence span. Boldface type p<.01
Table 4  Product-Moment Correlations for Old Adults Working Memory Spans

<table>
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<td>-.41</td>
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Note. BDS= backwards digit span, SP_WS1= self-paced one-syllable word span, SP_WS3= self-paced three-syllable word span, SP_RS= self-paced reading span, SP_SS= self-paced sentence span, T_WS1= timed one-syllable word span, T_WS3= timed three-syllable word span, T_RS= timed reading span, T_SS= timed sentence span

Testing the predictive relationship between word and reading span

To test the prediction that word span would predict reading span score a hierarchical regression was conducted with age, administration, one-syllable, and three-syllable word spans as the predictor variables and reading span as the dependent variable. Results are indicated in table 5.

The first regression analysis examined the contribution of age to reading span. Age was a significant predictor of reading span score, $t (83) = -2.03, p < .04$, accounted for 2.4% of the variance in reading span, $R^2 = .024, F (1,166) = 4.12, p < .04$.

The second regression analysis examined the contribution of administration procedure to reading span. Administration, though not a significant predictor, $p > .17$, contributed 3.5% of the variance in reading span scores over and above age, $R^2 = .035, F (2, 165) = 3.02, p < .05$.

The third regression analysis examined the contribution of one-syllable word span to reading span scores. One-syllable word span—a significant predictor of reading span, $t$
(164) = 4.37, \( p < .01 \)—contributed 13.6% of the variance in reading span over and above age and administration, \( R^2 = .136, F (3, 164) = 8.60, p < .01 \).

The final regression analysis examined the contribution of three-syllable word span to reading span performance. Three-syllable word span, also a significant predictor of reading span, \( t (163) = 4.99, p < .01 \), contributed 25.1% of the variance in reading span, \( R^2 = .251, F (4, 163) = 13.63, p < .01 \).

Taken collectively, these results suggest that word span performance, especially three-syllable word span, is a strong predictor of reading span.

Table 5  Summary of Hierarchical Regression Analysis for Reading Span

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>( R^2 )</th>
<th>Adj.( R^2 )</th>
<th>( \Delta R^2 )</th>
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</table>

*Note.* 1-s word span = one-syllable word span, 3-s word span = three-syllable word span. Boldface type \( p < .05 \)
Nelson Denny reading comprehension

Paired T-tests were conducted on young and older participants reading times and reading comprehension performance on the Nelson-Denny reading comprehension measures. Overall reading times for the seven Nelson-Denny passages did not differ significantly between the two age groups, all \( p 's > .05 \). A paired samples T-test was also conducted to determine if there was a significant difference between young and older participants’ reading comprehension performance on the Nelson-Denny task. Younger adults’ mean comprehension scores (\( M=20.45, SD=3.42 \)) were significantly greater than the older adults’ mean reading comprehension scores (\( M=17.14, SD=4.14 \)); \( t (41) = 4.43, p < .001 \).

One younger adult and seven older adults did not read all seven passages in the allotted time (20 minutes), and were thus unable to answer the comprehension questions for those passages. Therefore, two comprehension scores were calculated: a standard score and a ratio score. The standard score was the sum total points each participant earned on the comprehension measure and the ratio score was calculated by dividing the participant’s total points earned by the number of questions actually answered. Repeated measures ANOVA with scores (standard, ratio) as the within subjects variable and age group (young, old) revealed that there was a statistically significant main effect for scores, \( F (1, 82) = 2049.27, p < .001 \). There was also a statistically significant interaction between age and comprehension scores, \( F (1, 82) = 15.99, p < .001 \). Paired T-tests confirmed that there was a statistically significant difference between young and older adults’ ratio scores, \( t (41) = 3.94, p < .000 \). The younger adults mean comprehension ratio
scores (M = .74, SD = .126) were greater than the older adults mean comprehension ratio scores (M = .64, SD = .134).

Hypothesis 1: Word span predicts reading comprehension for both age groups

To test the prediction that word span scores would be correlated with comprehension scores for both age groups, Pearson-product moment correlations were computed between the timed and self-paced composite word span score (one- and three-syllable words) and Nelson-Denny ratio scores. An inspection of tables 3 and 4 demonstrates that, as expected, both self-paced and timed word spans correlated with reading comprehension better than self-paced and timed working memory spans for the young and older group.

Table 6  Product-Moment Correlations for Memory Span and Reading Comprehension

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</table>

Note. Boldface type p < .05
Hypothesis 2: Span task administration affects the correlation with reading comprehension

Pearson-product moment correlations were computed separately for age groups (young vs. older adults) and administration conditions (time vs. self-paced) between Nelson Denny ratio comprehension scores, composite word span scores (one- and three-syllables) and working memory composite scores (Waters and Caplan and Daneman and Carpenter).

The correlations between self-paced word span and Nelson-Denny ratio scores was higher for the older adults, $r = .37, p = .02$, as compared with the younger adults, $r = .29, p = .066$. However, a test of the correlations using Fisher’s $r$ to $z$’ transformation indicated that these differences were not significant, $z = .41, p = .68$. The correlations between self-paced working memory span and the Nelson-Denny ratio scores was higher for the younger adults, $r = .11, p = .50$, as compared with the older adults, $r = .06, p = .70$. Tests of these correlations failed to reach significance, $z = .16, p = .45$.

The correlations between timed word span and Nelson-Denny ratio scores was higher for the older adults, $r = .43, p = .005$, as compared with the younger adults, $r = .33, p = .04$. Fisher’s $r$ to $z$’ transformation for the correlations failed to reach significance, $z = .54, p = .60$. The correlations between timed working memory span and Nelson-Denny ratio scores was again higher for the younger adults, $r = .14, p = .38$, as compared with the older adults, $r = .01, p = .95$. Tests of these correlations failed to reach significance, $z = .66, p = .51$. 

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The observed patterns of correlations suggest that span task administration procedure does indeed alter the relationship between working memory span and higher-order cognitive abilities.

*Hypothesis 3: word span predicts reading comprehension better than working memory span*

To examine the prediction that word span would predict reading comprehension over and above working memory span, a series of hierarchical regression analyses were conducted on the composite word span and working memory composite scores. Analyses were conducted separately by age group and self-paced and timed administration.

The first regression analysis examined the contribution of younger adults’ self-paced word span and working memory performance to reading comprehension, as measured by the Nelson-Denny ratio scores. The two predictors (self-paced word span and self-paced working memory span) accounted for 8.3% of the variance in Nelson-Denny ratio scores, $R^2 = .083, F(2, 41) = 1.8, p > .19$ (see table).

The second regression examined the contribution of younger adults’ timed word span and working memory performance to reading comprehension, again using the Nelson-Denny ratio scores as the dependent measure. The two predictors (timed word span and timed working memory span) accounted for 10.7% of the variance in Nelson-Denny ratio scores, $R^2 = .107, F(2, 41) = 2.34, p > .11$.

The third regression examined the contribution of older adults’ self-paced word and working memory span to the Nelson-Denny ratio scores. The two predictors (self-paced word span and self-paced working memory span) accounted for 14.3% of the variance in Nelson-Denny ratio scores, $R^2 = .143, F(2, 41) = 3.24, p < .05$. 

Self-paced word span, which was entered first into the equation, explained 13.7\% of the variance in Nelson-Denny ratio scores, \( p < .02 \).

Self-paced working memory span added 0.6\% of the variance in Nelson-Denny ratio scores over and above the variance already accounted for by self-paced word span.

The final regression examined the contribution of older adults’ timed word span and working memory span performance to the Nelson-Denny ratio scores. The two predictors, timed word and working memory span, accounted for 20.2\% of the variance in Nelson-Denny ratio scores, \( R^2 = .202, F (2, 41) = 4.95, p < .01 \).

Older adults’ timed word spans, which were entered first into the equation, explained 18.5\% of the variance in Nelson-Denny ratio scores.

Old adults’ timed working memory spans added 1.8\% of the variance in Nelson-Denny ratio scores over and above the variance already accounted for by timed word span scores.

Taken collectively, the results of the regression analyses suggest that word span predicts reading comprehension performance better than working memory span for older, but not younger, adults. This prediction is especially true when the administration of the word span tasks is altered.
Table 7  Summary of Hierarchical Regression Analysis for Nelson-Denny Scores

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</table>

Note. Boldface type $p < .05$

Strategy interviews

Immediately following the self-paced and timed word span, reading span, and sentence span tasks, all participants were interviewed about how they remembered the target words in the task. Responses were coded using a scheme based on Turley-Ames and Whitefield (2003) and Friedman and Miyake (2004). Responses that included silently
or mentally repeating the words were coded as phonological strategies. Responses that included making mental associations between the target words, such as stories, songs, the contents of the actual stimuli, or some variation therefore that involved applying the meaning of the words to the participant’s reported strategy were coded as a semantic technique. Responses in which the participant reported visualizing the sentence or the word were coded as visual techniques. Because of the variability of responses to the interview questions, additional coding strategies were implemented post-hoc. For example, some of the participants would report repeating the stories that they had created out of the to-be recalled words. As this strategy entails both semantic and phonological processing, the decision was made to create additional, mixed response categories. The mixed categories included: phonological-semantic (participant reported both mentally repeating and making associations from the stimuli), phonological-visual (cases in which the participant reports both visualizing and repeating the target words), semantic-visual (the participant reports visualizing the words and making associations, and an “other” category for participants who reported using methods that did not qualify in the other categories.
Table 8 Definitions of Strategy Coding Scheme and Sample Responses

<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
<th>Sample Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phonological</td>
<td>Subvocally rehearsing the target words.</td>
<td>I repeated the words to myself.</td>
</tr>
<tr>
<td>Semantic</td>
<td>Generating relations between the target words.</td>
<td>I made a story out of the words.</td>
</tr>
<tr>
<td>Visual</td>
<td>Creating a mental image of the target words.</td>
<td>I pictured the words.</td>
</tr>
<tr>
<td>Phonological-semantic</td>
<td>Subvocally rehearsing &amp; creating associations between the target words.</td>
<td>I repeated the words to myself and made associations with the words.</td>
</tr>
<tr>
<td>Phonological-visual</td>
<td>Subvocally rehearsing &amp; mentally picturing the target words.</td>
<td>I repeated the words to myself and pictured the words.</td>
</tr>
<tr>
<td>Visual-semantic</td>
<td>Generating relations between &amp; creating a mental image of the target words.</td>
<td>I made a story out of the words and pictured the words.</td>
</tr>
<tr>
<td>Other</td>
<td>Responses that do no match the previously defined categories.</td>
<td>I counted the words.</td>
</tr>
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</table>

All means and standard deviations are reported below in table 9. Data collected from the strategy interviews were analyzed in a 2 (age group) x 2 (presentation format) x 3 (span task) repeated measures ANOVA. Although the 3-way interaction between presentation format, span task, and age group was not significant ($F(1, 82) = .625, p > .43, ns$), several of the lower-order comparisons were. Younger adults reported using a wider array of strategies across tasks compared to older adults which resulted in a main effect of age, $F(1, 82) = 9.26, p < .003$, partial $\eta^2 = .10$. Reported strategies also differed
by administration procedure, $F(1, 82) = 5.69, p < .02$, partial $\eta^2 = .07$. However, interactions between span task and presentation format, $F(1, 82) = 4.07, p > .56, ns$, age and span task, $F(1, 82) = .83, p > .36, ns$, and age and presentation format, $F(1, 82) = 2.65, p > .11, ns$, were not significant.

Paired T-tests were conducted on reported self-paced and timed strategies for each of the span tasks. There was a significant difference between self-paced and timed word span, $t(83) = 2.04, p < .05$ and sentence span strategies, $t(83) = 2.43, p < .02$, but not for the self-paced and timed reading span strategies ($t(83) = 3.6, p > .72, ns$). Reported strategies differed between young and older adults on the self-paced word span ($t(41) = 2.22, p < .03$), reading span ($t(42) = 2.5, p < .02$), and sentence span ($t(41) = 2.91, p < .006$) tasks. An inspection of the table of means suggests that younger adults employed more complex cognitive strategies (i.e. phonological-semantic or semantic-visual) during the span tasks, as compared with the older adults. Curiously, young and older adults only differed in their reported strategies for the timed administration of the reading span, $t(41) = 2.05, p > .05$, but not the word span, $t(41) = .52, p > .05$, or sentence span, $t(41) = 1.85, p > .07$ tasks.
Table 9  Means for the Strategy Interviews

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<td>.03</td>
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</tr>
</tbody>
</table>

Note. N=no strategy reported, P=phonological, S= semantic, V=visual, P-S= phonological-semantic, P-V= phonological visual, S-V= semantic visual, O= other. WS=word span, RS= reading span, SS= sentence span.
Figure 5. Frequency of young adults’ reported strategies.
Figure 6. Frequency of old adults' reported strategies.
Pearson-Product Moment correlations were computed for both self-paced and timed memory spans and reported strategies. An inspection of the correlation matrix in table 10 suggests that administration condition may change the relationship between span task performance and strategy use. For example, observe that the correlation between one-syllable word span and word span strategy is not significant in the self-paced condition \((r = .19, ns)\) but is significant in the timed condition \((r = .26, p < .05)\). The reverse appears to be true for three-syllable word span and word span strategy. Likewise, the magnitude of the relationship between self-paced reading span and self-paced reading span strategy increases from \(r = .34, p < .01\) to \(r = .36, p < .01\) for timed reading span and timed reading span strategy.

Interestingly, the relationships among the different self-reported strategies were significant for both administration conditions, suggesting that participants may rely on common memorial-based strategies regardless of task demands. For example, the correlation between self-paced reading and sentence span strategies was quite high in both the self-paced, \(r = .47, p < .01\), and timed, \(r = .45, p < .01\) administration conditions. That the correlations between reading and sentence span was higher for both conditions, as compared with the relationship between both measures and word span strategies, hints at the possibility that participants rely on common strategies for complex span tasks.
Table 10  Product - Moment Correlations for Memory Measures and Reported Strategies

<table>
<thead>
<tr>
<th>Measure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-Paced</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W_SPAN 1</td>
<td>.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W_SPAN 3</td>
<td>.33</td>
<td>.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R_SPAN</td>
<td>-.40</td>
<td>-.47</td>
<td>-.43</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_SPAN</td>
<td>.19</td>
<td>.22</td>
<td>.13</td>
<td>.07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WS_STRAT</td>
<td>.10</td>
<td>.32</td>
<td>.34</td>
<td>-.09</td>
<td>.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RS_STRAT</td>
<td>.22</td>
<td>.23</td>
<td>.19</td>
<td>-.20</td>
<td>.39</td>
<td>.47</td>
<td></td>
</tr>
<tr>
<td>SS_STRAT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timed</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>W_SPAN 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W_SPAN 3</td>
<td>.56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R_SPAN</td>
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<td>.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_SPAN</td>
<td>-.19</td>
<td>-.28</td>
<td>-.45</td>
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</tr>
<tr>
<td>WS_STRAT</td>
<td>.26</td>
<td>.18</td>
<td>.27</td>
<td>-.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RS_STRAT</td>
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<td>.08</td>
<td>.36</td>
<td>-.06</td>
<td>.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS_STRAT</td>
<td>.27</td>
<td>.18</td>
<td>.30</td>
<td>-.07</td>
<td>.41</td>
<td>.45</td>
<td></td>
</tr>
</tbody>
</table>

Note: W_SPAN 1 = one-syllable word span, W_SPAN 3 = three-syllable word span, R_SPAN = reading span, S_SPAN = sentence span, WS_STRAT = word span strategy, RS_STRAT = reading span strategy, SS_STRAT = sentence span strategy. Boldface type *p < .05.

Strategy surveys

To the question *during the experiment I used a special technique to help me remember the words*, the majority of participants responded positively in both the self-paced ($\chi^2 (2) = 74.77, p < .000$) and timed ($\chi^2 (2) = 87.5, p < .000$) experimental conditions. More participants responded positively in the timed ($N_{observed} = 68$), as compared with the self-paced responses ($N_{observed} = 65$).

To examine the effect of administration condition on strategy use, post-experimental responses were submitted to a 2 (age group) x 2 (strategy type) x 2 (frequency of strategy use) repeated measures ANOVA. Although the three-way interaction between age group, strategy type, and frequency was not significant, $F (1, 82) = 3.16, p > .08$, the main effect
of age was, $F(1, 82) = 4, p < .05, \eta^2 = .05$. The main effects of strategy and frequency, as well as the interaction between these variables and age, were not statistically significant, all $p's > .05$, but, the nearly significant interaction between age and strategy, $F(1, 82) = 2.17, p > .09$, suggested further investigation.

Paired t-tests indicated that the effect of time did have a significant effect on older, $t(41) = 2.10, p < .05$, but not younger adults, $t(41) = -.129, p > .90$, self-paced and timed reported strategies.

Examinations of the distribution of frequencies for both the self-paced and timed administration conditions indicate that the majority of participants (61.9% and 66.7% respectively) reported repeating the to-be-remembered words to themselves. Interestingly, there was no statistically significant difference between either session ($F(1, 82) = .181, p > .672$) or age groups ($F(1, 82) = .502, p > .481$) as to how frequently the reported strategy was employed during the experimental session.

Table 11  Means for Post-Experiment Interviews Question 2

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Young</th>
<th>Old</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Self-paced</td>
<td>Timed</td>
</tr>
<tr>
<td>Sent</td>
<td>.10</td>
<td>.05</td>
</tr>
<tr>
<td>Pie</td>
<td>.12</td>
<td>.12</td>
</tr>
<tr>
<td>Rep</td>
<td>.60</td>
<td>.64</td>
</tr>
<tr>
<td>P</td>
<td>.07</td>
<td>.14</td>
</tr>
<tr>
<td>O</td>
<td>.12</td>
<td>.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Self-paced</th>
<th>Timed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sent</td>
<td>.02</td>
<td>.07</td>
</tr>
<tr>
<td>Pie</td>
<td>.12</td>
<td>.17</td>
</tr>
<tr>
<td>Rep</td>
<td>.64</td>
<td>.69</td>
</tr>
<tr>
<td>P</td>
<td>.12</td>
<td>.05</td>
</tr>
<tr>
<td>O</td>
<td>.10</td>
<td>.02</td>
</tr>
</tbody>
</table>

Note: Sent= made a sentence with the words, Pie= pictured the words, Rep= repeated the words, P=put the words together, O= other.
Figure 7. Frequency of participants’ surveyed strategies.
CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Discussion

The present study investigated how normal aging, administration procedure, and strategy contribute to the relationship between working memory span task performance and higher-level cognitive ability, namely reading comprehension. College-age and older participants completed three measures of short-term verbal memory, backwards digit span, and a one- and three-syllable word span task, as well as two measures of verbal working memory, the Daneman & Carpenter reading span and the Waters and Caplan sentence span. Comprehension ability was measured by the Nelson-Denny reading comprehension test. Additionally, participants' cognitive status was assessed via three standard neuropsychological measures: the Logical Memory subtest, the abbreviated Boston Naming Test, and the Mini-Mental Status questionnaire. Vocabulary was assessed using the Vocabulary subtest of the WAIS. Finally, reading rate was measured as the time taken for participants to read aloud 37 unrelated sentences.

The following section will contain a discussion of the results of the present study as each relates to their respective predictions set forth at the beginning of the document.

Younger vs. older adults' baseline reading times

The results of the present yielded a significant difference between the two age groups' mean reading times on the baseline reading task. One explanation for the
observed findings is cognitive decline associated with normal aging impairs older adults’ ability to read sentence structures. In their review of the literature on age-related changes in language abilities, Wingfield and Stine-Morrow (2000) discuss the accumulated experimental evidence that younger and older adults generally perform comparably to one another in sentence-level reading tasks. Task demands, such as the presentation of unique sentence structures or the anticipation of a quiz following the activity, may elicit mild-to-moderate age-based differences. Because participants in the current study were not required to recall any of the baseline reading stimuli, this explanation may be safely eliminated.

An alternative explanation for the findings is that the requirement to read the sentence stimuli aloud may have contributed to the observed differences in reading rate. Although articulation of the baseline sentences was not directly measured in the present study, previous research has identified positive associations between age-related physiological changes in the speech-sensorimotor system and comparatively longer articulation rates in aging adults (Smith, Wasowicz, & Preston, 1987; Benjamin, 1982). The cognitive costs associated with age-related differences in speech production have also been examined (e.g. Kemper, Herman, & Lian, 2003). Kemper et al (2003) found that older adults exhibited comparatively greater difficulty in producing complex sentences when instructed to included a specified number of words (experiment 1) or certain verb types (experiment 2).

Younger vs. older adults’ word span performance

For both age groups, span scores were higher for one-syllable words compared with three-syllable words. This finding is consistent with the word-length effect, first
described by Baddeley, et al (1975), which holds that recall for words with fewer syllables should be better than words with more syllables. That older adults exhibited impaired recall for three-syllable words is consistent with previous research (Miller & Johnson, 2004; Kynette, et al., 1990). Kynette, et al (1990) found that younger adults’ recall of one-, two-, and three- syllable words was superior to that of older adults. In that study, both young and older adults exhibited decreased recall for three- syllable words, as compared with one-syllable words. The present study replicated those results. The younger adults showed higher recall spans for the self-paced administration of the one- and three-syllable word spans, and for the timed administration of the three-syllable words, as compared with older adults.

Friedman and Miyake (2004) reported that administration condition (participant-administered vs. experimenter-administered) had no effect on participants’ recall of one-, two-, and three-syllable words. The main effect of administration condition for the present set of results suggests that pacing the presentation rate of the stimuli exerted some influence on participants’ recall of one- and three- syllable words. Indeed, the t-test results showed that younger adults recalled on average more words than the older adults under self-paced and timed conditions, barring, of course, timed one-syllable word span. Therefore, one conclusion from the present set of results is that age, word length, and administration procedure all contributed to word span performance.

However, an examination of the effect sizes for each significant word span-related effect indicates that word length (partial $\eta^2=.42$) accounted for a greater percentage of the variance in word span scores than administration condition (partial $\eta^2=.16$) or age (partial $\eta^2=.13$).
What are the theoretical implications for the results of the present study? According to Salthouse’s (1996) slowing view, differences in span performance may be due to age-related changes in the speed at which mental operations can be executed. From this perspective, one might have anticipated that limiting the amount of time available to read and store the target words would have had little impact on the younger adults’ scores and greater effect on the older adults’ scores. In contrast to this prediction, however, younger adults’ word span recall suffered with the introduction of time constraints. Although older adults’ one-syllable word span recall did not suffer as a function of time constraints, their three-syllable word recall did. Thus, speed of processing did not explain the observed differences in word span performance.

Another possibility is that age-related declines in span task performance are due to diminished working memory processing resources (Baddeley, 1986). The large effect size for word length found in the present study provides some support for this perspective; however, a significant age x word length interaction would be necessary to qualify this hypothesis.

One reason for the lack of significant interactions between age, word length, and administration may result from the randomized span presentation. According to the inhibition deficit perspective (Zacks, Hasher, & Li, 2000), age-related differences in span performance may be minimal or non-existent when the to-be-recalled stimuli are presented in random, rather than the traditional ascending, list order. Thus, randomizing the span presentation order may have negated the expected interactions between age, administration, and word length, but, as evidenced by the significant main effects, each variable still individually contributed to word span scores.
Younger vs. older adults' reading span performance

It was predicted that younger adults would achieve higher working memory spans on the complex span measures, relative to older adults. Surprisingly, there was little support for this prediction. The lack of age-related differences in recall performance for the Daneman and Carpenter reading span measure is surely antithetical to numerous cognitive aging studies. It is, however, congruent with May, Hasher, and Kane (1999), who found no reliable age differences on the reading span task performance when the spans were presented in descending, as compared with the traditional ascending, order. The age differences for traditional and descending performance, they argued, were due to older adults experiencing greater retrieval errors when inhibiting irrelevant information, such as previous target words from smaller span levels. Conway, Kane, Bunting, Hambrick, Wilhelm, and Engle (2005) have also suggested that randomized span presentation order may reduce the possibility that participants would employ task-related strategies, such as anticipating the preceding number of to-be-recalled items.

Lack of significant age differences on the sentence span task may also be explained by the effect of randomized span presentation. Fewer aging studies have used the Waters and Caplan sentence span task, as compared with the reading span task; but, studies that have used the sentence span task have found reliable age differences (Waters & Caplan, 2005). To my knowledge, this is the first study to employ random span presentation with this task. The main effect of task suggests that the added processing component of the sentence span task may account for some of the overall variability in working memory span.
One might have anticipated that the addition of time constraints would impair older adults’ recall performance on the reading span task, relative to younger participants. As evidenced by both the ANOVA and patterns of bivariate correlations, time appeared to have no such effect for the older adults. Similar accounts can be found in the literature. For example, Gick, Craik, and Morris (1988) found that limiting the time available to verify sentences on a reading span task produced no significant age variation in task performance. The present experiment builds on Gick et al.’s study by demonstrating that limiting the amount of time available to read the sentence stimuli also produces no significant age effects. This finding reinforces the inhibition-deficit account of age differences on the reading span task: the major contributing factor to observed age differences on the reading span task was the presentation of increasingly longer lists of target items to be recalled. At the very least, it can be concluded that time constraints had no effect on the recall performance of the present sample of healthy, older adults.

**Interrelations between word and sentence span**

There are a number of interesting features regarding the pattern of correlations between the different memory measures. For both age groups, the correlation between three-syllable word span and the working memory measures was stronger than the relationship between one-syllable word span and the working memory measures. This finding suggests that the effects of increased task demands on verbal memory performance are parallel among the different measures. In other words, three-syllable word span correlated more strongly with the more complex measures because the intrinsic increased memory demands (storing one vs. three syllables in this case) requires more mental resources. Friedman and Miyake (2004) found that administration
conditions had a significant effect on the relationship between word span and reading span performance. The reported relationship between word span and reading span was .48 in the participant-administered condition and .55 in the experimenter-administered condition (F&M did not report if these correlations differed significantly). The results of the present study are completely different. Excluding the unusually low correlation between self-paced one-syllable word span and reading span \( (r = .13) \), the pattern of correlations between simple and complex measures of memory span was stronger in the self-paced as compared with the timed administration condition for both age groups.

Methodological distinctions between the present study and the Friedman and Miyake study may account for the discrepancies in correlation patterns. For example, randomized span presentation was used in the present study, but not in the Friedman and Miyake study. Second, differences in span task administration procedures (self-paced v. timed in the present study, participant-administered v. experimenter administered in the Friedman and Miyake study) may also explain the observed differences. Last, although Friedman and Miyake reported using different syllable lengths in the word span lists, the reported bivariate correlations did not specify outcomes-by-syllable, but rather overall word span performance.

Waters and Caplan (1996) reported a correlation of \( r = .62 \) between their sentence span and the Daneman and Carpenter reading span, when testing undergraduate students. Obviously, that pattern of correlations was not replicated in the present study. The observed differences in scores between the present study and the Waters and Caplan study may also be due to methodological differences, such as smaller sample size in the present study \( (n = 94 \text{ (WC)} \text{ vs. } n = 84 \text{ (present study)}) \), or differences in the testing
procedure, to the degree that the present study featured randomized presentation of the six span levels. Also, Waters and Caplan (1996) did not specify the correlation between composite scores for the CS sentences and reading span.

**Vocabulary will be a significant covariate of the working memory tasks**

Superior vocabulary performance by older adults is a common finding in aging research and, as such, has inspired important theoretical and methodological questions (Bowles, Grimm, & McArdle, 2005; Hedden, Lautenschlager, & Park, 2005, Verhaeghen, 2003; Salthouse, 1988). Vocabulary may represent aspects of crystallized intelligence (Cattell, 1987) or represent the organization of lexical information in long-term memory (MacKay & Abrams, 1998). Hedden, Lautenschlager, and Park (2005), suggest that older adults may rely on vocabulary as an environmental support on memory tasks, in the absence of direct task-related support. The nature of the relationship between span task performance and vocabulary knowledge remains uncertain; but studies have demonstrated a positive relationship between age, vocabulary, and working memory span. For example, McCabe and Hartman (2003) tested if vocabulary, span task reaction time, and perceptual speed predicted older adults’ speed of processing on span tasks. Despite not being a significant predictor variable, they did find that vocabulary was both a significant covariate and positive correlate of word and working memory span, yet failed to find significant interactions.

The present sample of older adults demonstrated superior performance on the WAIS-R vocabulary subtest. Although vocabulary had no effect on word span scores, it was observed that vocabulary scores covaried with and were related to working memory span. Distinctions in the methodology and testing apparatus in the present and previous aging
studies, however, prevent any meaningful generalizations in terms of the contribution of verbal knowledge to working memory span. For example, the vocabulary subtest of the WAIS-R, which was used in the present study, is known to elicit substantially different results compared to other measures of vocabulary such as the vocabulary subtest of the Shipley Institute of Living Scale (Verheaghen, 2003). Factors such as education and test format (open response v. multiple-choice) are hypothesized to covary with age and may influence test results. A focus for future research is the precise nature of the relationship between vocabulary and working memory span task performance.

**Word span performance vs. reading span performance**

As discussed, for both young and old participants, there was a strong association between scores on the word and the working memory span measures. In particular, three-syllable word span performance was strongly related to reading span. However, the strength of the observed relationship appeared to depend on both the participant’s age and how the task was administered. For example, the relationship between the older adults’ three-syllable word span and reading span was stronger under timed, as compared with self-paced, testing conditions. The reverse was true for the younger adults—the relationship between three-syllable word span and reading span was stronger under self-paced testing conditions.

The results of the regression analysis confirmed the supposed predictive relationship between age, word, and working memory span, yet negated the possible contribution of task administration to this relationship. These findings are consistent with McCabe and Hartman (2003) and also extend previous research (Craik & Rabinowitz, 1985) by demonstrating that word-length, in this case one- v. three-syllables, may further
contribute to observed age-related variance in reading span, whereas administration procedure does not.

Younger and older adults’ reading comprehension vs. word span performance

As was predicted, younger adults did indeed perform superior to older adults on the Nelson-Denny reading comprehension measures. This finding is consistent with previous work (i.e. Norman, et al, 1993). One possible explanation for this finding is that older adults were unable to read all of the material in the twenty-minute time period and, therefore, were unable to answer all of the reading comprehension questions. The ratio scoring procedure would control for differences in number of comprehension questions answered. Another explanation could be that age-related changes in long-term memory may impair older adults’ ability to comprehend verbal information; yet, an inspection of the mean vocabulary scores clearly illustrates that older adults are not impaired in their vocabulary abilities, and in fact, perform superior to younger adults. The significant age-related differences in Logical Memory II recall scores (see table 1) also suggests age-related decline in long-term memory. Indeed, a test of the relationship between both age groups’ Logical Memory scores and Nelson-Denny ratio scores was significant, respectively $r = .35, p < .02$ and $r = .33, p < .03$. A third possible explanation for the present results may be age-related decline in reading rate or, fourth, reading comprehension. An exploration of this possibility will be examined momentarily.

The present study succeeded in replicating the results of Friedman and Miyake (2004), who found that the correlations between reading comprehension were higher for the experimenter-administered word span scores, as compared with the participant-administered word span scores. This finding was true for both age groups, as indicated in
the table of correlations. In their experiment, they also demonstrated that, when controlling for the effects of word span scores, reading span remained a significant predictor of reading comprehension for the experimenter-administered, but not participant-administered testing conditions. In the present study, the results of the hierarchical regression analyses indicated that for the older adults, timed word span scores contributed more to the variance in their reading comprehension scores (18.5%) than timed working memory span (1.8%). The older adults’ self-paced word spans contributed more to the variance in reading comprehension than self-paced working memory spans (13.7% vs. .6%), but still less than the timed administration.

The results of the regression analyses suggest that age, in addition to span task administration, may have differentially contributed to the relationship between lower- and higher- level cognition. One line of evidence that supports this theory is that the results of the present study also succeeded in replicating the results of Norman, Kemper, and Kynette (1992), who found age-related differences in reading comprehension using the same measure (Nelson-Denny) and scoring procedure (ratio) of reading comprehension. Based on the findings in that study, the authors suggested that the observed difference in reading comprehension was best explained by age-related decline in reading comprehension abilities and not reading rate. Because those authors used the traditional paper-pencil test format, they were unable to measure reading time. In the present study, however, we not only replicated the finding that younger adults’ ratio reading comprehension scores were superior to that of older adults, we also failed to find significant age-related differences in reading time for the seven reading passages.
Strategy use vs. reading span performance

The present study assessed how participants retain target span task words in two ways: first, participants were interviewed prior to completing each span task, and second, participants completed a short survey at the conclusion of each testing session. Analyses of both strategy interviews and post-experimental strategy surveys indicate that both young and older participants relied on strategies to help them retain target words in memory. Both the strategy interviews and the post-experiment strategy surveys also demonstrate that the majority of participants in both age groups reported using a phonologically-based strategy to maintain the words in memory under both self-paced and timed span task administration conditions. These results are in conflict with the results of Friedman and Miyake (2004), who found that participants reported using phonological strategies more often during the participant-administered span task testing condition (82%), as compared with the experimenter-administered testing condition (59%). The results of the strategy interviews in the present study revealed that 82% of participants reported using a phonological-based strategy when tested under self-paced span task conditions and that 81% percent reported using this strategy under timed conditions. The post-experiment surveys in the present study also support this finding, 61% and 66%, respectively. On the other hand, the results of the strategy interviews indicated a nearly similar percentage of participants reported using semantic strategies in both the self-paced (55%) and timed (63%) testing conditions. These results are similar to Friedman and Miyake (55% in the participant-administered and 45% in the experimenter administered conditions), with the exception, of course, that participants in the present study reported using semantic techniques more often in the experimental condition.
Salthouse (1991), among others, has argued against the notion that age-related differences in cognitive task performance may be due to age-related differences in strategy use. According to this view, cognitive decline associated with normal aging prevents older adults from even considering the possibility of employing a memory strategy. The results of the present study do indicate that fewer younger adults reported not using a strategy to help them remember the to-be-recalled items than older adults in both the self-paced (M = 2, SD = 1.73 v. M = 5.67, SD = 3.79) and timed (M =3.33, SD = 3.21 v. M = 7, SD = 3.61) testing conditions. Nevertheless, the majority of participants, both young and old, reported using a strategy. For example, the average number of older participants who reported using a phonological strategy in the self-paced condition (M = 13.33, SD = 2.52) nearly approximates the average number of younger adults who reported using a phonological strategy in the self-paced condition (M = 15.67, SD = 3.06). Curiously, more old participants reported using a semantically-based technique in the timed condition (M = 12.67, SD = 1.15) as compared with their younger counterparts (M = 5.33, SD = 2.08). Regardless, these results demonstrate that age-related declines in cognition do not differently impair older adults’ ability to formulate or use memorial-based strategies.

The self-reported data obtained in the present study indicates that older adults generally rely on phonological and semantically-based strategies to aid them in the recall of span task items. The decision to use either of these strategies may depend on how the task is administered. Younger adults, on the other hand, may employ a wider range of strategies to aid their recall of target items, which may also vary depending on the task administration conditions. For example, more young adults reported using a semantic-
visual strategy in the self-paced administration condition as compared with older adults, M = 7, SD = 1 v. M = 1, SD = 0. Also, more young adults reported using a phonological-semantic technique in the timed administration condition than older adults, respectively M = 5.67, SD = 1.53 v. M = 4, SD = 2.65. Again, these results suggest that younger adults may rely on a greater diversity of memorial-based strategies than older adults, but they do not suggest that older adults are incapable of using or contemplating using strategies.

Limitations and Future Research

Inconsistencies with previous research and unexpected outcomes in the present set of results may be reflective of limitations in the methodology and measures used. Regarding working memory span task performance, it is possible that permitting participants to freely recall target items (rather than the traditional serial order) would provide a more accurate picture of storage capacity. Some participants may, for example, feel discouraged from recalling an item because they might be uncertain if the item occurred in a given sequence. This question could be tested experimentally by manipulating task instructions, to the degree that some participants are told to recall span task items in correct serial order and a control group of participants completing the same span task would be instructed to recall as many task items as possible.

Individual differences in reading ability may have also contributed to the observed difference in span task performance. Throughout the course of the present study it was observed that some participants misread task stimuli. This observation was apparent only for tasks that required the participant to read elements out-loud (i.e. baseline reading and the Daneman and Carpenter reading span task). Recognition of a misread item during or
after the item is presented to the participant may interfere with their ability to target task items (i.e. sentence-final words). A test of this hypothesis might include, for example, an audio record of the testing session, which could be subsequently compared with actual task stimuli for a point value.

The results of the present study suggest that other individual difference variables, namely vocabulary skill, contribute to the relationship between lower and higher level cognitive abilities, but the precise nature of this relationship remains ambiguous. Although vocabulary was a significant covariate and correlate of working memory, it is unclear how precisely word knowledge contributes to the active processing and storage of verbal information. Future studies employing more advanced statistical procedures, such as structural equation modeling, may provide a clearer picture of the causal relationship between age, processing and storage abilities, vocabulary, and reading comprehension.

One question that may be raised based on the results of the present study is how does imposing time limits affect older adults’ comprehension of discourse reading material? The significant differences between younger and older participants’ reading comprehension scores in the present study may be due to the time-constraints imposed on the Nelson-Denny reading comprehension measure. Recall, the participant is told at the beginning of the task that they have twenty minutes to read and answer as many task items as they can. Empirical examples of the benefits of environmental support abound in the cognitive aging literature.

The present experiment included two measures of strategy use during and following span task administration. Although informative, descriptive data is generally not conducive to forming causal arguments. In the present study participants were
interviewed about how they remembered the span task words. The obvious shortcoming in this approach is the assumption that participants are consciously aware of, and can accurately verbalize, their on-line cognitive processes while completing intellectually challenging experimental tasks. Moreover, the somewhat subjective nature of the coding of the responses also makes interpretation of the collected data challenging. The post-experiment survey was one way to remedy the arbitrary nature of the interviews, yet those too required a fair amount of self-awareness and reflection on the part of the participants. One path to a causal account of strategy use on span task performance might be to employ more methodologically sound testing apparatus, such as eye tracking devices.

**Conclusions**

The conventional wisdom among memory researchers is that because working memory span tasks require the active processing and storage of information (whereas short-term memory span tasks require the passive storage of information), working memory span tasks are more reliable indicators of complex cognitive activities, such as reading comprehension. The relationship between these different measures could be considered in a linear fashion: short-term memory span predicts working memory span predicts reading comprehension. Since the inception of short-term memory measures, numerous studies have provided evidence to support this notion and different theoretical accounts have been postulated to explain this relationship.

Recent studies, however, suggest that extraneous factors, both within the measure itself and within the participant sample, may exert some influence on the predictive relationship between these measures. Concerns about the internal nature of span task
measures have inspired numerous studies and one of the landmark findings was the report that the presentation order of span task items may influence individual outcomes on span measures (May, Hasher, & Kane, 1999). The storage of previous items may interfere with the test-taker’s ability to learn new items, thereby decreasing the reliability of the person’s memory span. More recently, it was also reported that span task administration procedures, such as limiting the available time to read the task stimuli, may influence the predictive relationship between verbal span tasks and reading comprehension (Friedman & Miyake, 2004). Naturally, such findings have had serious implications for theories about the relationship between lower and higher order cognition.

Participant attributes, such as age, have been reported to covary with span performance so often that such effects have been taken to represent the norm, rather than the exception, although exceptions do occur under certain circumstances. Numerous theories have been put forth to explain why age effects are such a common finding on working memory span tasks. One theory is that reductions in the processing and storage mechanisms in the working memory system brought on by the consequences of normal aging yields declining performance. Another theory holds that with progressive aging is the impaired ability to filter irrelevant from relevant information (Hasher & Zacks, 1988). A third theory is that age-related decline in cognitive performance is attributable to a reduction in the speed in which mental operations are executed (Salthouse, 1996). Because attempts at resolving the various theories of age-based effects on working memory span tasks have been unable to successfully rule out or control the various contributing factors to age-associated differences in span task performance, it has been
suggested that these individual theories may operate as a collective picture of cognitive aging, rather than independent accounts.

Several variables have long been suspected of influencing span task performance, but most prominently among them are participants' general intellectual abilities. Scores on standardized intelligence measures, such as vocabulary and digit-symbol tasks, are typically strongly associated with span scores (Daneman and Green, 1986; Salthouse, 1996). The implications for the relationship between working memory span task performance and performance on general intellectual assessments remains uncertain; however, some researchers have suggested that this relationship may be indicative of an individual's ability to focus and sustain their attention—a critical feature of the central executive component of the working memory model (Baddeley, 1986; Conway, Kane, & Engle, 2003).

Another potential contributing factor to span task performance is how the user retains the to-be-recalled stimuli in memory. McNamara and Scott (2001) and Turley-Ames and Whitfield (2003) reported that instructing participants to rehearse the target items on a working memory span task substantially altered their scores. More recently, Friedman and Miyake (2004) found that participants who reported using visual strategies (picture the to-be-recalled stimuli) performed better on span tasks as compared with participants who reported rehearsing or forming semantic associations with the to-be-recalled stimuli. Although the study of strategy use and span task performance is limited to mostly descriptive approaches to data collection, it does raise some plausible concerns about individual differences and the underlying cognitive processes associated with the processing and storage of information.
What, then, did the present study contribute to the current state of knowledge on working memory span tasks? Congruent with the conventional wisdom, increased processing and storage demands contributed to span scores. All participants exhibited stronger performance on the word span tasks and weaker performance on the working memory span tasks. As task complexity increased from passive storage to processing and storage, performance declined. Also in-line with the current state of knowledge was the predictive relationship between simple and complex measures of memory span. The results of the zero-order correlations and hierarchical regression analyses indicated that performance on simple verbal span tasks predict verbal working memory span tasks scores. Three-syllable word span in particular was a strong predictor of reading and sentence span. Inconsistent with the current state of knowledge, however, was the finding that word span performance was a stronger predictor of reading comprehension than working memory span. This finding, at the very least, casts some doubt on the conventional wisdom about the validity of the hypothesized relationship between processing and storage and higher-level cognitive abilities.

The present experiment included two variations on the typical span task experiment: randomized span presentation and self-paced and timed administration. The randomization of the span levels is hypothesized to decrease the influence of interference from previously learned material. Since the present study included no direct test of randomized and traditional ascending span levels, it is not certain how the randomized span levels may have contributed to the present set of results. However, the results discussed here are consistent with previous outcomes (May, Hasher, & Kane, 1999) that report significant differences using a-typical span presentation. Administration procedure
had little effect on the present set of results. On the one hand, participants did perform better on the self-paced administration of the word span task, as compared with the timed administration. On the other hand, administration procedure did not have any significant effect on participants' working memory span scores, nor did it contribute significantly to the relationship between word and working memory span, or the relationship between working memory span and reading comprehension.

As discussed previously, participant characteristics are known to have a strong impact on span task scores. Age was the primary participant characteristic of focus in the present study. Based on the available literature, it was anticipated that the younger participants would have performed significantly better than the older adults on all of the experimental tasks. This prediction was not wholly supported. Although the younger adults did exhibit superior performance on the word span task, the effect of age was not significant for the working memory span tasks. The significant differences in word span performance suggests that diminished working memory capacity, specifically in the phonological loop, as a consequence of normal aging may contribute to age-related differences in memory performance. The lack of significant age-effects on the working memory span tasks, however, is consistent with the inhibition-deficit account of aging, because, in accordance with theory, age-related differences in span task performance should be minimal or non-existent when the threat of proactive interference is eliminated by randomizing the order of span levels.

The results of the present study suggest that age is a contributing factor to the relationship between lower- and higher-level verbal abilities. First, younger adults exhibited superior performance on the Nelson-Denny reading comprehension measure.
Second, although both young and older participants' word span were significant correlates of reading comprehension, the results of the regression analysis indicated that older adults' word spans were significant predictors of reading comprehension. Theory dictates that age-related decline in the capacity of the working memory system may account for identified age-differences in word span performance. Thus, the strong relationship between older adults' word span and reading comprehension suggests that diminished working memory capacity may explain age-related differences in reading comprehension performance.

As previously discussed, participants' general intellectual abilities may influence span performance. In the present study, mental speed and vocabulary were measured using two common sub-tests of the WAIS-R intelligence assessment. Participants' mental speed was assessed using the symbol-symbol and digit-symbol measures. Age-related differences on these measures would suggest that declines in the speed of processing may contribute to span performance (Salthouse, 1996). However, no age-based discrepancies were identified in the present sample, thus speed of processing was not a contributing factor to the present set of results. On the other hand, performance on the vocabulary subtest was strongly related to word and working memory span, suggesting that verbal knowledge is an important contributing factor to verbal span task performance.

It should be noted here that verbal knowledge remains relatively unimpaired by the effects of normal aging. Older adults typically perform superior to college-age adults on vocabulary measures, and the present set of healthy older adults was no exception to this finding. Thus, age may have been the contributing factor to the relationship between vocabulary scores and memory span. The reasons for the relationship are unclear, but the
high association between vocabulary and verbal span task performance may indicate that older participants rely on information in semantic memory as an aid to recall in the absence of task-specific aids, as suggested by Hedden, Lautenschlager, and Park (2005).

Previous research suggests that how participants retain target stimuli in memory may contribute to span task performance (Mcnamra & Scott, 2001, Friedman & Miyake, 2004). The present sample of individuals reported a range of span task strategies, most prominently rehearsal of and, to a lesser degree, forming semantic relationships among the target items. That the majority of participants reported rehearsing the to-be recalled stimuli is consistent with Baddley’s (1996) notion of reliance on sub-vocal rehearsal in the phonological component of the tripartite model of working memory. The type of strategies reported appeared to be influenced by task demands, task administration, and age.

It is possible, but not positive, that strategy use did not contribute to span task performance. Analyses of the data obtained from the participants’ strategy interviews and post-experimental surveys indicated that strategy use did not differ significantly as a function of task, but rather by age and administration condition. It has already been established that age and administration condition had an effect on word, but not working memory span task performance. If strategy use had any effect on working memory span tasks, then greater age or administration differences might have been observed. The evidence therefore suggests that any effects of strategy use on span task performance might have been localized to the simple span tasks.

In sum, the results of the present study raised some questions with regard to the current state of knowledge about working memory span tasks. The relationship between
verbal span task performance and higher-level verbal abilities identified in the present sample suggests a reexamination of previous research. Likewise, the contribution of cognitive decline associated with normal aging to span task performance also requires reexamination in light of the present findings. Last, it remains uncertain how intellectual abilities and strategy use contribute to span task performance, particularly when individual difference variables, such as age, have been taken into account.
APPENDIX I

POST ASSESSMENT QUESTIONNAIRE

Post-Assessment Questionnaire

RECORD!

1. How did you remember the words?

2. Did you use any special techniques to help you remember the words?

3. (If yes) could you tell me more about how you remembered the words?

4. Some people say they use special strategies to help them remember the words…

5. How often did you use this strategy to help you remember the words?
APPENDIX II

POST-EXPERIMENT SURVEY

Participant ID_____ Date__________ Experimenter_____

Post-Experiment Survey

To be completed at the end of the session.

During the experiment I used a special technique to help me remember the words. Circle one.

Yes No

Place a checkmark (✓) next to the statement that most strongly describe you.

To help me remember the words I....

- Made a sentence with the words
- Pictured the words in my head
- Repeated the words to myself
- Put the words together
- Other

If you selected other, please explain on the space below:

__________________________________________________________________________
__________________________________________________________________________

Circle the answer that most strongly describes you.

During the experiment, how often did you use the technique to help you remember the words?

I did not use a technique Some of the time Most of the time All of the time
Month day, Year  
Participant’s name  
Address line 1  
Address line 2  
Zip  

Dear participant,

Welcome to the Cognition in Aging Laboratory. We are currently working on research for memory and aging and thank you for your interest in participating in our study. Your appointment is scheduled for day, month and date at time. We are located in the Central Desert Complex (CDC) building #6, with a sign on the door labeled: “Cognition in Aging Research CDC 620”.

We have enclosed parking instructions, a map of the parking areas available to use on campus, transit instructions, and a parking permit. Please make sure to scratch off the date and time of use for the parking permit upon arrival to the campus on the date of your scheduled appointment. Failure to scratch off the date and time of use could result in a parking ticket and fee.

Please note that the experimenter that will be running your appointment does not arrive until thirty minutes before the appointment. If you happen to arrive earlier than a half an hour before your scheduled time, please feel free to check to see if anyone is in the lab or have a seat on the bench located in the courtyard outside of the lab just a few feet southwest of the lab door.

If there are any questions regarding your appointment or any other concerns, please contact us at 895-4652 or 895-5619. If you need to cancel or reschedule your appointment, please do so within 24 hours. Thank you again and we look forward to seeing you.

Sincerely,

Paul Schroeder
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