

Individual Differences in Reading Are More Than Just Working Memory: The Case for Available Long-Term Memory

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ABSTRACT - Working memory, as defined by Baddeley's multiple component models (Baddeley, 2001, Baddeley and Hitch, 1974) has often been touted as an important, if not the most important, source of individual differences in reading comprehension. Recent investigations have made the argument that the increased availability of long-term memory plays an important role in comprehension. Participants ($N = 54$) completed measures of working memory, available long-term memory and comprehension. Multiple regression analysis tested the hypothesis that measures of increased availability of long-term memory elements account for unique variance in comprehension distinct from the variance accounted for by traditional working memory measures. Results indicated that available long-term memory accounted for unique variance and hold important implications for models of comprehension.

The hypothesis that Bradley's model of working memory accounts for the greatest amount of variance in comprehension has been accepted widely in reading and cognition literature. Daneman and Carpenter's (1980) reading span task has been employed throughout the literature to determine if individual differences in comprehension can be accounted for by the attention driven capacity of working memory. Several studies have demonstrated a correlational relationship between span tasks, including reading span, operation span and digit span, and comprehension (see Daneman and Merikle, 1996 for a review). Despite the influence of Baddeley's (see Baddeley, 1986, 2001; Baddeley & Hitch, 1974) multiple components model of working memory, criticism has arisen that the estimated capacities of the storage systems are too small to explain complex learning and comprehension activities.

The criticisms levied against the multiple components model are centered on the estimated capacities of the attention-dependent storage systems being too small to explain complex learning and comprehension activities. For example, Anderson (1983) attempted to simulate various forms of cognitive performance, reporting the need to increase the size of working memory well beyond previously described estimates. Employing computer simulations of complex cognitive activities, Broadbent (1993) arrived at similar conclusions as Anderson. Other theorists have also stated that the empirically derived capacity of working memory cannot explain necessities for complex processing involved in reading. Ericsson and Kintsch (1995), proposed that traditional

working memory capacity limits do not provide a tenable explanation of the individual differences found in highly practiced complex skills, such as language comprehension. In order to compensate for the limitations of attention-driven working memory limits, comprehension has been hypothesized to require the activation and immediate availability of long-term memory nodes (Just & Carpenter, 1992; Just, Carpenter, & Keller, 1996).

Hypotheses regarding immediate access to long-term memory elements that are available for processing but are not actively maintained by attention processes, have led to the proposal of alternative models of working memory (e.g., Anderson, 1983; Anderson, Reder, & Lebiere, 1996; Cowan, 1995; Ericsson & Kintsch, 1995; Just & Carpenter, 1992; Oberauer, 2002). These working memory proposals have important differences, but a feature germane to all of them is that activation processes (or related long-term memory processes) along with attention-driven mechanisms more effectively define capacity limits that constrain complex processing activities than attention-driven working memory alone. Furthermore, it is suggested that attention processes and activation processes are capacity limited in different ways (Cowan, 1995, 1999). At this time, the direct empirical evidence regarding these issues is rather limited.

These more recent models of working memory and of comprehension include the activation of background knowledge as an essential component in the reading process. Measuring the portions of long-term memory that are in a state of activation or availability, has primarily taken the form of priming measures. Priming effects have been demonstrated in a wide variety of tasks including but not limited to semantic categorization (e.g., Rips, Shoben & Smith, 1973), lexical decisions (e.g., Meyer & Schvaneveldt, 1971), item and recognition (e.g., Ratcliff & McKoon, 1978). Woltz and Was (2006, 2007) found that minimal processing in attention-driven working memory leads to relatively long-lasting semantic and associative priming. In accord with the distinctions from previous work, in the current study the terminology chosen to describe this highly active information distinguishes that the memory processes investigated involve the readiness of semantically related information in long-term memory rather than the just-processed information. Therefore, we will refer to the priming affects as measures of available long-term memory. This also avoids limiting the interpretation of increased availability to either spreading activation or skilled retrieval mechanisms, as the use of some prior terminology would imply.

Woltz and Was (2006, 2007) found that information processed in attention driven working memory increases the availability of long-term memory nodes related to the information processed in working memory. In a subsequent study, it was also determined that the relationship between working memory and listening comprehension was mediated by the availability of long-term memory (Was and Woltz, 2007). Was and Woltz (2007) used listening comprehension measures designed specifically for that study, which limits the ability to directly compare the results to other studies in which working memory measures were correlated with reading comprehension. The current study employed a measure of reading comprehension similar to those used in previous research a common measure of working memory capacity, and a more traditional measure of semantic priming.

Just and Carpenter (1992) proposed that both processing and storage are mediated by activation and that this capacity varies among individuals. Furthermore, this limited activation capacity should predict individual differences in reading comprehension. Based on this assumption individual differences in strength of available long-term memory would lead to differences in comprehension, and account for variance not accounted for by tasks of attention-driven working memory capacity. However, the reading span task (Daneman and Carpenter, 1980) used to measure the activation construct is more precisely a measure of the storage and processing capacities of working memory. Therefore, the current study applied a direct measure of available long-term memory. The task is a measure of semantic priming and therefore reflects a more precise measure of the increased availability of long-term memory elements. In an attempt to determine if available long-term memory accounts for differences in reading comprehension above and beyond that accounted for by measures of attention-driven working memory, an alternative to the reading span task was also used as the measure of attention-driven working memory.

Much of the work in working memory and comprehension research has been completed using correlational studies. In line with these previous individual differences studies, the current study was designed to test the above hypothesis in an experimental setting and applying regression techniques.

Method

Participants

Fifty-four undergraduate students, 39 females and 15 males, all native English speakers, enrolled in an introductory educational psychology course at a large state university were given course credit for their participation in the study. The median age of the sample was 20 ($M = 22.57$, $SD = 6.25$).

Apparatus

Testing took place in a well-lit room containing six microcomputers. Participants performed the experimental tasks on PC's with 17" SVGA monitors and standard keyboards. Soundboard panels separated the microcomputers allowing for 1-6 participants to complete the tasks at a time. Programming of all tasks was completed with E-Prime® software (Schneider, Eschman, & Zuccolotto, 2002). E-Prime® controlled the stimulus presentation, timing, and data collection.

Materials

Available long-term memory was measured using a repeated trial semantic comparison task (Woltz, 1990). Each comparison consisted of two words presented in the center of the computer display, one on top of the other separated by approximately 2.5cm. Each comparison was preceded by an attention queue (two asterisks, one above the other in the center of the screen) presented for 250ms followed by a blank screen for 250ms. The two words were then presented and remained on the screen until the subject responded by pressing either the *L* key (for like) or the *D* key (for different) depending on whether the subject judged the words to be synonymous or unrelated. Subjects were instructed to respond as quickly as possible without sacrificing accuracy. Response

feedback was also designed to encourage attention to response speed without inducing errors. Trial response latency followed correct responses for 1000ms, while the word *incorrect* followed errors for 1000ms. In addition, subjects were presented summary feedback of percent correct and mean latency after each block of 24 comparisons and were reminded to respond as quickly and as accurately as possible.

The 24 experimental comparisons were preceded by two warm-up comparisons. The 24 experimental comparisons included twelve prime comparisons and twelve target comparisons. One half of the primes and one half of the targets were negative match comparisons. Targets are arranged at lags of one, two and three intervening trials. Therefore, the first three trials were primes, the fourth was a target with a lag of one (the prime being trial two) the fifth trial a target at lag three (the first comparison trial its prime), and the sixth trial a prime with a lag of two and so on until participants have responded to all twenty four trials. Participants completed seven blocks of trials counter balanced across subjects.

The reading tasks were designed to task participants' attention-driven working memory capacity. This task presented participants with nine passages each seven to 12 sentences long. The passages were presented one sentence at a time in the center of the computer screen. The participants were told that the next sentence would appear each time they pressed the spacebar and they would not be able to return to the previous sentence. After completing each passage the participants answered four multiple-choice questions regarding the passage. Passages included either a list of subjects or items that must be remembered to complete the multiple-choice questions correctly.

Working memory was measured using the ABCD working memory (Kyllonen and Christal, 1990; Woltz, 1988). Each of the 24 trials consisted of the participants interpreting three visually presented statements that together defined the order of the letters *ABCD*. One statement defined the order of *A* and *B* (e.g., *B comes after A*; interpreted as *AB*). Another statement defined the order of *C* and *D* (e.g., *D comes before C*; interpreted as *DC*). The third statement defined the order of *AB* relative to *CD* (e.g., *Set 1 comes after set 2*; interpreted as *Set2 Set 1* or *DC AB*). The ordering of the three statements and the ordering operations in each statement was varied across trials. Processing time for each statement is self-paced with a limit of 20 seconds. After all three statements are interpreted; participants select a response from an alphabetized list of eight possible orders. The 24 experimental trials were divided into two 12 trial blocks.

Results

For all variables, latency and accuracy were combined to create a speed measure. Table 1 displays the descriptive statistics of latency and accuracy for all three variables. The transformation of latency and accuracy [$\text{accuracy}/(\text{latency}/60000)$] results in a metric interpretable as number correct per minute. This transformation includes the relevant variance of both accuracy and latency and results in a more normal distribution (Woltz, 1990).

The available long-term memory measure was calculated by first applying the speed transformation to all trials, then by regressing primed trials (targets) unto unprimed trials (primes) and calculating an overall mean residual score for each participant. Only data from positive match comparisons were used as previous research has demonstrated that

priming is typically only demonstrated in positive match trials (Woltz, 1990; Woltz & Was, 2006).

Table 1
Descriptive Statistics for Accuracy and Latency of All Three Variables

Variable	Accuracy (Proportion Correct)		Latency (in Milliseconds)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Reading Comprehension	.70	.15	6217	1364
ABCD Working Memory	.50	.24	2963	785
Word Meaning Comparisons				
Primes	.88	.07	1229	369
Target	.94	.05	1142	378

Table 2 shows the product moment correlations between ABCD WM, available long-term memory and the reading measure. Both ACBD WM and available long-term memory both showed moderate significant correlations with the reading task as well as with each other. Available long-term memory was still significantly correlated with reading when variation in ABCD WM was controlled for ($r = .60, p < .01$). When individual variation in available long-term memory was controlled for ABCD WM was still significantly correlated with reading ($r = .37, p < .01$).

Table 2
Correlations Among Three Variables

Variables	1	2	3
1. Reading Speed	1.00		
2.ABCD WM Speed	.42	1.00	
3. Comparison Speed Residuals	.63	.22	1.00

To determine whether priming accounts for unique variance in reading that is not accounted for by working memory, a multiple regression analysis of reading onto ABCD WM and available long-term memory was conducted. In the regression analysis ABCD WM was entered first followed by available long-term memory. In reading, ABCD WM accounted for 17% of the variance ($R^2 = .17, F(1,52) = 10.97, p = .002$). Thirteen percent of the variance in reading accounted for by ABCD WM was unique variance, while the remaining 4% of the variance was shared with available long-term memory¹.

Available long-term memory accounted for another 30% of the variance in reading, R^2 change = .30, F change (1,51) = 29.49, $p < .001$. Together, ABCD WM and available long-term memory accounted for 48% of the variance in reading, $R^2 = .48, F(2, 51) = 23.23, p < .001$.

The analyses support the theoretical view that complex cognitive tasks require processing limits beyond the empirically derived limits of attention driven working memory (e.g., Anderson, 1983; Broadbent, 1993; Ericsson & Kintsch, 1995). Another important implication of the current analysis is that individual differences in the

activation of long-term memory play a significant role in comprehension. Individual differences in activation of long-term memory information account for a large amount of variance in reading comprehension. This finding is compatible with theories of comprehension that include the availability of background knowledge as an integral portion of the comprehension process (e.g., Ericsson & Kintsch, 1995; Kintsch, 1988; 1998).

Discussion

Results of the regression analysis support the hypothesis that available long-term memory accounts for unique variance in reading comprehension. The reading task used in this study was chosen in part due to the expected relationship with the attention-driven working memory measure. In order to determine if priming accounted for unique individual variance in the reading task it was necessary to have at minimum a moderate correlation between the working memory measure and reading. It was determined that the priming measure did account for unique variance in the reading measure.

Haarman, Davelaar, and Usher (2003) recently found that conceptual span accounted for unique variance after controlling for reading span and word span. It is important to note the difference between semantic short-term memory and the increased availability of long-term memory. They developed the conceptual span task to measure the construct of semantic short-term memory (Martin, Lesch & Bartha, 1999; Potter, 1993), a device used in the storage of lexical-semantic item representations. They also describe semantic effects in immediate recall tasks that cannot be explained by long-term memory (Haarman and Usher, 2001) as evidence that semantic memory is part of a short-term verbal store. Haarman et al. (2002) designed a task to measure semantic STM that was based in recall of previously encoded words. The measure of available long-term memory in the current measure requires participants to respond to previously unseen information that was semantically related to previously encoded information. It is clear that the two tasks are measuring very different mechanisms.

Largely, the analyses support the theoretical view that complex cognitive tasks require processing limits beyond the empirically derived limits of attention driven working memory (e.g., Anderson, 1983; Broadbent, 1993; Ericsson & Kintsch, 1995). Another important implication of the current analysis is that individual differences in the increased availability of long-term memory play a significant role in language comprehension. That is, the ability to quickly access information semantically related to recently processed information supports the comprehension process. Individual differences in the increased availability of this information account for a large amount of variance in reading comprehension. This finding is compatible with theories of comprehension that include the availability of background knowledge as an integral portion of the comprehension process (e.g., Ericsson & Kintsch, 1995; Kintsch, 1988; 1998; McNamara, 1997).

¹ Unique variance contribution of ABCD WM was calculated as the square of the semi-partial correlation with the criterion measure.

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