WORKING MEMORY INTERVENTION: A READING COMPREHENSION APPROACH

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ABSTRACT

For any complex mental task, people rely on working memory. Working memory capacity (WMC) is one predictor of success in learning. Historically, attempts to improve verbal WM through training have not been effective. This study provided elementary students with WM consolidation efficiency training to answer the question, Can reading comprehension be improved by strategic updating of WMC and utilization of episodic memory during reading?
We report preliminary data from 10 5th grade students who took three pretests to measure each student's 1) ability to comprehend sentences of varying lengths, 2) ability to decode English-like words (Snowling, 1986), 3) working memory capacity (Weschler, D, 2008). 5 students were chosen to receive a working memory training that consists of 2 sessions a week for 4 weeks. In the training sessions, the students were presented with a series of progressively longer sentences and were asked to choose a picture to demonstrate comprehension. All 10 students took 2 post-tests, alternate versions of the working memory capacity and sentence comprehension pre-tests.
The working memory and sentence comprehension data were analyzed using a one-tailed t-test. A priori power analysis indicated that I need 35 subjects in each of the 2 groups to have 95% power for detecting a large sized effect when employing the traditional .05 criterion of statistical significance.
I expect that this training will change the strategies elementary readers use to update their WMC while reading to understand progressively more complex sentences. If successful, this training will dramatically affect reader's interest and confidence, and can serve as a model for elementary reading programs.

KEYWORDS

Working memory, reading comprehension, episodic memory

1. INTRODUCTION

Although multiple models of working memory have been explored since the mid-twentieth century, Baddeley and Hitch's model is often referenced in current research addressing the relationship between working memory and reading comprehension (Gathercole, 1998). Baddeley (2003) states that, regarding his multi-component model compared to others, "in general, deviations from other models represent differences of emphasis and scope, rather than direct conflict." A basic understanding of Baddeley's working memory model is helpful in discussing the relationship between working memory and reading comprehension.

Baddeley (2003) and Hitch's working memory model originally consisted of three components, the central executive, the phonological loop, and the visuo-spatial sketchpad. The phonological loop stores auditory memory traces for a few seconds before they fade, unless an articulatory rehearsal strategy is applied to maintain the memory, while the visuo-spatial sketchpad acquires visual input, which is limited in capacity to about three to four objects (Baddeley, 2003). The phonological loop and the visuo-spatial sketchpad are regulated by the central executive, which Baddeley (2003) described as "the most important but least understood component of working memory." Baddeley (2003) identified one function of the central executive component as resource control; the ability to allocate attentional resources when two or more mental activities are being performed simultaneously. As a result of his research into the central executive component of working memory, Baddeley (2001) added a fourth component, which he calls the episodic buffer. The episodic buffer is a "temporary multidimensional store… that allows a range of different subsystems to interact" and whose main function is to "bind together different sources of information to form integrated chunks." (Baddeley, 2001)

Because the comprehension of language, whether spoken or written, "entails processing a sequence of symbols that is produced and perceived over time," the relationship between comprehension and working memory becomes evident (Just and Carpenter, 1992). Reading in particular requires storage of "intermediate and final computations" as ideas are constructed and integrated from the "stream of successive words in a text" (Just and Carpenter, 1992).

Swanson (1992) studied working memory in skilled and less-skilled readers to determine if differences are related to a general system or not. Of interest to Swanson's study are two theories regarding the relationship between working memory and poor reading skills. First, in Daneman's (1980) model, working memory resources are related to reading skill, in that readers with inefficient skills overload working memory capacity, while efficient readers have adequate working memory resources left to store reading products. This would mean that "individual differences in working memory performances are tied to the specific processing task of reading," not differences in working memory capacity (Daneman, 1980).

A second model of interest to Swanson (1992) was Turner and Engle's, which suggests that the working memory capacity of poor readers is smaller than that of strong readers. This model hypothesizes that working memory capacity is independent of reading skill, and therefore weaker working capacity is not a consequence of poor reading skills, but that the lower capacity leaves fewer resources available for performing reading and non-reading tasks (Swanson, 1992).

Swanson (1992) reasoned that the inconsistency might be attributed to two issues: 1) "the psychometric qualities of the working memory tasks" which suggests "that individual differences in the relationship between working memory and reading reflect a number of factors other than working memory operations" and 2) "previous studies have relied…on single measures to reflect verbal or nonverbal working memory operations." Swanson's exploration of these issues "does not eliminate the possibility that processing efficiency at a language level drives this relationship between working memory and cognitive performance" (Swanson, 1992). While Swanson's work did not conclusively support either Daneman or Turner and Engle, "the findings…suggest that working memory performance can be enhanced and that such performance appears to improve predictions of reading" (Swanson, 1992).

Montgomery, Magimairaj and O'Malley (2008) also report a correlation between working memory and children's ability to understand complex sentences.. Their study suggests that "comprehension accuracy for complex sentences was significantly associated with two of the three working memory mechanisms-attentional resource control/allocation and speed of processing" (Montgomery, Magimaiaj and O'Malley, 2008). These results support Turner and Engle's model which highlights the role of working memory capacity in reading comprehension, inviting further investigation into working memory interventions.

Daneman and Carpenter (1983) also studied how the integration of information between and within sentences is related to working memory. Their research explored how integration processes "may stress the limits of working memory capacity and contribute to the purging of verbatim wording" on which readers rely when comprehending over sentence boundaries. Their study further supported their previous research, as they argue that the results suggest, again, that even at the sentence level, it is "the conjoint effective use of processes and storage" which causes individual differences in working memory abilities (Daneman & Carpenter, 1983).

An fMRI study by Oleson, Westerberg, and Klingberg (2003) is more encouraging to working memory intervention research. They report that, following a 5 week training on working memory tasks, fMRI results in healthy, adult human subjects show an increase in brain activity in the middle frontal gyrus and superior and inferior parietal cortices, areas of the brain related to working memory. Oleson (2003) concludes from these results that, although "working memory capacity has traditionally thought to be constant," it can be improved by training.

While Swanson, Montgomery, and Oleson offer research supporting working memory interventions, Melby-Lervåg and Hulme (2012) conducted a meta-analysis of the effectiveness of working memory training and concluded that, while the current literature reveals improvements in working memory, these improvements are restricted to the tasks practiced during training and not generalized to other tasks requiring working memory, like reading comprehension.

Because there still exists conflicting theories regarding the possible benefits of working memory training, and the dearth of research utilizing an intervention based on sentence-level comprehension, this study will utilize a training task which specifically addresses the comprehension of sentences, in the hopes that it will not only improve working memory function, but will address a comprehension component as well.

One possibility is that such training can encourage development of processing strategies that enhance comprehension performance by utilizing *event templates* in long-term memory, while freeing up the working memory capacity. Earlier fMRI and EEG studies (Newman et al., 2013; Malaia et al., 2009) showed that individuals vary with regard to frequency and timing of attempts to consolidate incoming information in the working memory with existing event representations, or templates, in the long-term memory. Prolonged and repeated use of these strategies can lead to neural changes that enhance both online comprehension and recollection of content in reading (Newman & Malaia, 2013).

Research in working memory indicates that working memory capacity is related to reading comprehension, but that research on the affect of interventions to improve working memory capacity has proven to generalize to complex working memory tasks. To further explore these findings, the research question is: Can reading comprehension be improved by strategic updating of WMC and utilization of episodic memory during reading? The researcher's hypothesis is that a carefully designed reading comprehension intervention which specifically trains working memory in processing complex sentences will result in gains in working memory capacity as measured by a backward span task. Gains in reading comprehension of extended narrative text are beyond the scope of the current project.

Teachers, parents, and school administrators interested in the reading success of students would be interested in an intervention that meets a specific and diagnosed need, such as low reading comprehension paired with identified poor working memory capacity.

2. METHODOLOGY

Because a predominance of literature addressing working memory capacity supports the notion that working memory capacity is static, this study attempts to address the issue from the stance of strategic use of working memory by providing an intervention for elementary students low working memory capacity, and explore whether this training will generalize to affect the results of a number-related working memory task

2.1 Participants

The study tested 11 fifth grade students (age M=10.9, SD=0.83, 7 females) attending a privately funded school, the primary function of which is to serve children from low-income households. All participants competed informed assent forms approved by the IRB of University of Texas at Arlington; consent was also obtain from each student's parent or guardian.

2.2 Experimental Design

All participants completed two tasks: a backward span task to determine working memory capacity, and a baseline sentence comprehension task. The backward span task measures the working memory capacity of the participants by asking them to recall an increasingly larger set of numbers from end to beginning. The sentence comprehension task was designed to measure the participant's ability to comprehend sentences as the length of each sentence become longer, increasingly taxing working memory capacity. The backward span task was performed until the participant reached failure. The sentence comprehension task was comprised of 18 sentences of varying lengths.

2.3 Backward Span Task

Beginning with a series of two one-digit numbers and increasing until the unable to recall in reverse order the series of numbers, the subject is asked to listen to the series of numbers, and then restate them in reverse order until an upper limit of correct recall is reached (see Figure 1).

2 digits 4 8
2 5
3 digits 3 7 2
5 8 6
4 digits 2 8 9 3
0 8 5 9
5 digits 4 7 3 2 1
6 3 1 5 2
6 digits 6 0 9 3 4 8
8 5 6 9 2 4

Figure 1. The Backward Span Task

2.4 Sentence Comprehension Task

The sentence comprehension task consisted of a randomly presented sentences ranging in length from 5 to 19 words. A memory probe element was included at either the beginning, middle, or end of the sentence. After reading the sentence aloud, the participant viewed 2 pictures and chose the one that best matched the meaning of the sentence (see Figure 2).

1. The boys played baseball well. (beginning)

2. The raccoons watched me paint the fence. (beginning)

3. Mom served us a healthy green salad for dinner. (middle)

4. When the ambulance arrived, Mark left the scene of the accident. (beginning)

5. Milo ran around the apple tree, jumped the fence, and shouted, “You can’t catch me!” (middle)

Figure 2. Sample Intervention Sentences

2.5 Task and General Procedure

11 fifth grade students from a self-contained classroom performed a baseline sentence comprehension task, Backward Digit Span pre-test, and a pseudoword reading task. One participant dropped out of the study after pre-testing. The remaining participants were divided into two groups of 5 students each, the experimental (those receiving the intervention, age *M*=10.8, *SD*=0.84, 3 females) and the control (those not receiving the intervention; *M*=10.6, *SD*=0.89, 4 females).

The 5 participants in the control group then participated in an intervention consisting of a working memory training two days a week for four weeks. The intervention consisted of students reading aloud sentences, and then identifying a picture which most accurately illustrated the sentence (see fig. 2). During the course of the intervention the sentences were gradually lengthened to 31 words. Following the intervention, both groups performed the Backward Digit Span; each participant also completed an alternate version of the sentence comprehension tasks in a post-test procedure (the versions administered as pre- and post-tests were balanced across participants).

2.6 Data Analysis

Accuracy and response time from sentences in pre- and post-intervention testing, and backward digit span were analyzed using a between-subject ANOVA with factor (Pre/Post).

3. RESULTS

A between-group repeated measures ANOVA analysis of Pre/Post measures (accuracy and response time for all sentences/sentences with probe words at the beginning, middle, and end/sentence lengths of 5, 7, 9, 11, 15 and 19 words; Backwards Digit Span) revealed a Pre/Post x Group interaction, showing that the response time of the intervention group was significantly lowered on sentences with the comprehension probe appearing in the middle of the sentence (F (8,1)= 7.329, p<.027; from M=3155 msec, SD=353 msec, to M=2355 msec, SD 357 msec in intervention group, compared to non-intervention group pre-test RT M =2333 msec, SD=353 msec, and post-test M=2434, SD 357 msec), and for 5-word sentences (F(8,1)=4.874, p<.058, from M=3197 msec, SD=415 msec, to M=2136 msec, SD 153 msec in intervention group, compared to non-intervention group pre-test RT M =2224 msec, SD=415 msec, and post-test M=2340, SD 153 msec). These results suggest improved automaticity of access to short-term memory in the intervention group.

Additionally, pre- and post-intervention Backward Digit Span Task results decreased for the intervention group (F(8,1)=8.333, p<.02; intervention group, from M =3, SD = 0.34, to M=2.6, SD=0.4; control group, from M=3.2, SD=0.34, to M=4.6, SD=0.4). Possibly, this indicates less resource allocation to the executive component controlling working memory manipulation as a result of higher resource allocation to the executive component controlling recall (as indicated by the response time results above). No other significant effects or interactions were found (p>.05).

4. DISCUSSION

The research question asked whether the training in consolidation of verbal working memory content to long-term memory reference would improve performance on a general (numerical) working memory task. The data did not support the idea that verbal working memory consolidation training would improve working memory more generally, as measured by the Backwards Span Task. However, analysis of the pre- and post-test data taken from the Sentence Comprehension Task did indicate improvement in the intervention group participants' performance in three ways: 1) participants more accurately recalled sentence elements that occured in the middle of the sentence, 2) participants processed sentence meaning in 5-word sentences more quickly as evidenced by faster response times, and 3) participants appeared to lower resource allocation to working memory manipulation, as opposed to recall and maintenance.

A limitation to this study was its small sample size. A priori power analysis indicated that this study needs 24 subjects, 12 in each groups, to register a large size effect of the intervention (f-.4).when employing the traditional .05 criterion of statistical significance. In addition, for 5th grade students, the Sentence Comprehension Task (pre- and post-test) might have been more sensitive with sentences longer than 15 words; so it is possible that the training task as it is would be better suited to younger participants.

5. CONCLUSION

This study is the first one to indicate that training in consolidating verbal information can improve individual performance on complex tasks requiring verbal working memory updates. While response time (indicating automaticity of the performance) was improved in the intervention group, performance on the Backward Digit Span task was lower post-intervention. It is not clear whether the training allowed the participants increased executive control of their working memory resource allocation, or improved the ability to switch attentional resources from working memory to long-term (semantic) memory. Overall, however, the results of this study indicate that it is possible to enhance individual executive component of working memory by short-term targeted training, and could lead to the development of materials for teachers to improve student reading comprehension at the sentence level.

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