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Improving Reading Strategy for Comprehension: "Does Recall Compete with Working Memory Manipulation?"

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Abstract

We investigated whether reading comprehension could be improved by strategic updating of working memory during reading, by providing upper elementary students with working memory consolidation training. We report data from ten fifth-grade students, half of which underwent strategic reading comprehension intervention. Response time data indicated that training in consolidating verbal information increased automaticity of recall. However, this improvement negatively correlated with post-training performance on Backward Digit Span, indicating possible tradeoffs between resource allocation toward the component of executive function moderating maintenance/recall, or toward the component moderating manipulation of working memory content

Introduction

Reading research indicates that working memory capacity is related to reading comprehension [1,2]. Disappointingly, attempts to improve working memory capacity have not been shown to generalize to complex tasks, such as reading comprehension [3,4]. At the same time, teachers, parents, and school administrators interested in the reading success of students are looking for an intervention that meets a specific diagnosed need, such as low reading comprehension paired with identified poor working memory capacity. To better understand how such an intervention can be developed, we need to consider the models of working memory (WM) and its use in reading comprehension: the classic Baddeley model, and the current brain-based models of WM and its management.

The most widely-use model of working memory is that of Baddeley [5,6]. The original model, constructed to explain behavioral data, consisted of three components: the central executive, the phonological loop, and the visuo-spatial sketchpad. Phonological loop was the term for the short-term store and rehearsal of sound-based information (spoken words), while visual sketchpad was assumed to hold visual information. Later, a component termed "episodic buffer" was added, which could allow for integration of information across different modalities, such as visual and auditory. All of the above were considered "slave systems" to the central executive component. Baddeley [6] identified the function of the central executive component as resource control: the ability to allocate attentional resources to mental activities performed simultaneously. As reading, specifically, requires storage of "intermediate and final computations" as ideas are constructed and integrated from the "stream of successive words in a text" [7], the role of executive component in reading comprehension is paramount. Specifically, as research on increasing working memory capacity has not been successful [8], it was hypothesized that the strategies in WM use, and executive control of it, rather than WM capacity per se, are at the root of high performance on cognitive tasks [9].

Recent advances in neuroimaging research suggest that the central executive component of working memory consists, in fact, of separate executive functions [10-14]. The dual access++ model of Nee et al. [15] suggested a three-way distinction among the executive component controlling manipulation of WM content (ventral LPFC), the component modulating focus of attention (WM updates, dorsal LPFC), and the component responsible for intrusion resistance.

The present study approached the task of improving comprehension of complex sentences by utilizing recent findings that efficient working memory updates (strategic re-allocation of attention for comprehension and retrieval) are used by highly efficient readers. Neural studies have shown that highly skilled readers use rapid, online strategies of information consolidation, quickly re-coding incoming information to references to semantic (long-term) memory [16,17]. Behavioral literature [18] also reported positive correlation between children's ability to understand complex sentences, and the speed of attention reallocation among items in working memory. Thus, the present experiment was constructed to investigate whether the training in strategic WM updating might improve reading comprehension and recall.

Methodology

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 completed informed assent forms approved by the IRB of University of Texas at Arlington; consent was also obtained from each student's parent or guardian.

Experimental design

All participants completed two tasks: a Backward Digit Span task [19] to determine the executive working memory capacity, and a baseline sentence comprehension task. The sentence comprehension

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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 sentence comprehension task was comprised of 18 sentences of varying lengths.

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. For example, to probe comprehension of a word at the beginning of the sentence, the sentence “The raccoons watched me paint the fence” would be followed by a two pictures – one of a raccoon family, and another of a pair of squirrels (Figure 1).

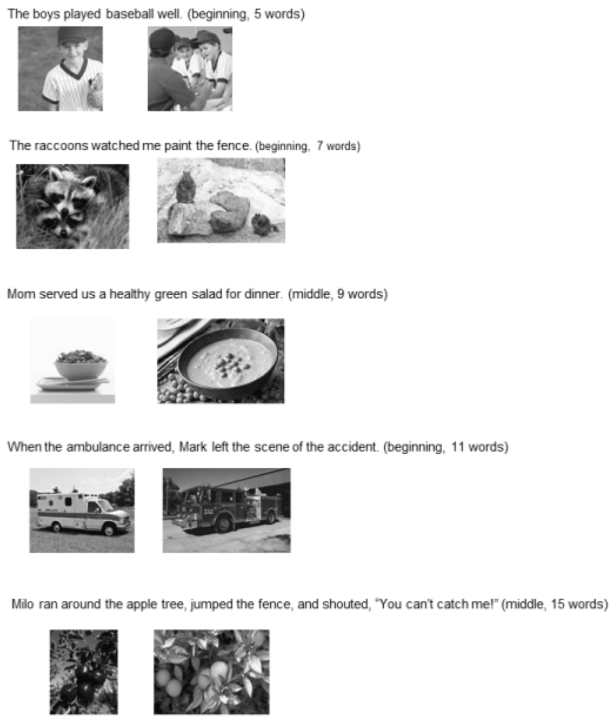

Figure 1: Sample Intervention Sentences. The location of the word tested by the picture probe is noted in parenthesis (beginning, middle, or end of the sentence), along with the sentence length (number of words).

Task and general procedure

11 fifth grade students from a self-contained classroom performed a baseline sentence comprehension task, Backward Digit Span [20] pre-test, and a pseudo word reading task [21]. 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 intervention group then participated in training that consisted 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 (Figure 1). 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).

Data Analysis

A priori power analysis indicated that this study needs 26 subjects, 13 in each groups, to register a medium size effect of the intervention (f=0.3), when employing the traditional .05 criterion of statistical significance [22-24]. In data analysis, the effect of intervention on Backward Digit Span was assessed using between-subject ANOVA with Pre/Post factor. Then, accuracy and response time from sentences in pre- and post-intervention testing (response times and accuracy, separately for each sentence length and probe word position) were analyzed using a between-subject ANCOVA with factor (Pre/Post), using pre-testing Backward Digit Span as a covariate.

Results

Pre- and post-intervention Backward Digit Span results revealed main effect of Pre/Post, (F(8, 1)= 8.333; p<.02; $ep2$=.510), and Pre Post x Group interaction (F(8, 1)= 27.000; p<.001; $ep2$=.771). Overall, Backward Digit Span decreased for the intervention group from M=3, SD=0.34, to M=2.6, SD=0.4. In control group, the result improved from M=3.2, SD=0.34, to M=4.6, SD=0.4, likely due to testing experience. Decreased performance on Backward Digit Span in the intervention group possibly indicates the tradeoff in resource allocation: fewer resources are allocated to the executive component controlling working memory manipulation (necessary for backward digit span task), as a result of higher resource allocation to the executive component controlling focus of attention during retrieval (necessary for responding to the comprehension probe).

A between-group repeated measures ANCOVA analysis of Pre/Post measures for response times to mid-sentence probe words revealed a Pre/Post x Span interaction (F(7,1)=8.872, p<.021, $ep2$=.559), and Pre/Post x Group interaction (F(7,1)=17.638, p<.004, $ep2$=.716) showing that, when controlling for pre-intervention WM manipulation ability, the response time of the intervention group was significantly lowered on sentences with the comprehension probe appearing in the middle of the sentence (from M=3195 msec, SD=349 msec, to M=2344 msec, SD=381 msec in intervention group, compared to non-intervention group pre-test M=2293 msec, SD=349 msec, and post-test M=2445, SD=381 msec). The shorter the length of response times to sentence probes, the higher is the automaticity of memory access [25,26]. Thus, these results suggest improved automaticity of access to memory in the intervention group. No other significant effects or interactions were found (p>.05).

Thus, the two significant results observed in the study pertained to increase automaticity of memory access in the intervention group, indicative of improvement in general comprehension [26], and the shif in allocation of executive attention from WM manipulation to retrieval, as evidenced by decreased performance of the intervention group on backward digit span task.

Significance

This study investigated whether the training in consolidation of verbal working memory content to long-term memory reference could improve performance on a general (numerical) working memory 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 two ways: 1) participants in the intervention group more accurately recalled sentence elements that occurred in the middle of the sentence, and 2) participants in the intervention group appeared to lower resource allocation to working memory manipulation, as opposed to recall and maintenance. The latter is best explained in the framework of the Dual ++ selection model, which proposes that ventral stream from pre-frontal cortex is tasked with both selective maintenance of memory trace (used for retrieval), and WM content manipulation [15].

A limitation to this study was its small sample size as compared to power analysis. In addition, for some of the 5th grade students, the Sentence Comprehension Task (pre- and post-test) appeared too easy, and they mentioned it during the post-study de-briefing. Then, it is possible that the task and training would be better suited to younger participants.

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.

As the present results indicate competing resource allocation between the two executive components (maintenance vs. content manipulation), it is possible that main effect of our intervention was in training the executive system in resource allocation for reading comprehension task. The question then arises – is it possible to develop a more general intervention focused on optimization of resource allocation for the task (for maintenance vs. memory content manipulation)? As our results indicate, appropriate selection of executive resources improved recall automaticity, but diminished performance on the task where manipulation of memory contents was needed. An intervention design that would train the participants in utilizing the more appropriate executive strategy might be beneficial for both reading comprehension, and mathematical tasks, which require students to manipulate and update memory content.

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