Journal of Applied Research in Memory and Cognition 5 (2016) 368–383

Contents lists available at ScienceDirect

Journal of Applied Research in Memory and Cognition

journal homepage: www.elsevier.com/locate/jarmac

Word Problem Solving, Working Memory and Serious Math Difficulties: Do Cognitive Strategies Really Make a Difference?

H. Lee Swanson*

University of California-Riverside, United States

A randomized control study investigated the role of strategy instruction on problem-solving solution accuracy in elementary school children with math difficulties MD ($N = 162$) who varied in working memory capacity (WMC). Comparisons were made of three strategy conditions that combined general (verbal and/or visual heuristics) and specific strategies (materials condition that include a controlled attention component of training), a fourth condition that focused only on specific strategies (materials-only) and an untreated control condition. Three important findings emerged: (1) strategy outcomes were moderated by WMC such that children with high WMC outperformed children with low WMC on all post-test measures, (2) the effectiveness of strategy conditions on post-test targeted (problem solving), near transfer (calculation) and far transfer (operation span, fluid intelligence) measures were significantly improved with specific strategies (material-only) than with the combination of general and specific strategies, and (3) treatment advantages related to the specific strategy condition were related to increasing controlled attention across training sessions relative to the other conditions. Taken together, the results suggest that among children with MD, children with higher WMC outperformed those with lower WMC suggesting that WMC serves as a bottleneck on both targeted and transfer measures.

Keywords: Problem solving, Cognitive strategies, Working memory, Math difficulties, Math disabled

Math word-problem solving constitutes one of the most important mediums through which children can potentially learn to select and apply strategies necessary for coping with everyday problems. Unfortunately, according to the National Mathematics Advisory Panel (2008) and to PISA (Programme for International Student assessment assessments; OECD, 2012a), U.S. children show substantial weaknesses when asked to solve word problems relative to other achievement domains and in comparison to other industrialized countries, which suggests a need to understand the cognitive mechanisms and processes that underlie word-problem solving. There is some recent evidence to suggest that one domain-general process, working memory (WM), may play an important role in problem solving and treatment outcomes in children who suffer from math difficulties (e.g., Fuchs et al., 2014; Swanson, Kehler, & Jerman, 2010). This connection becomes apparent when the steps related to problem solving are taken into consideration. For example, solving a word problem, such as "15 dolls are for sale, 7 dolls have hats. The dolls are large. How many dolls do not have hats?" involves a variety of mental activities. Children must access pre-stored information (e.g., 15 dolls), access the appropriate algorithm (e.g., 15 minus 7), and apply problem-solving processes to

Author Note

H. Lee Swanson, Area of Educational Psychology, University of California-Riverside, United States.

This paper is based on a study funded by the U.S. Department of Education, Cognition and Student Learning in Special Education (USDE R324A090002), Institute of Education Sciences, awarded to H. Lee Swanson. The author is indebted to Cathy Lussier, Amber Moran, Danielle Guzman-Orth, Olga Jerman, Loren Albeg, Catherine Tung, Dennis Sisco-Taylor, Kenisha Williams, Garett Briney, Kristi Bryant, Debbie Bonacio, Beth-Brussel Horton, Sandra Fenelon, Jacqueline Fonville, Alisha Hasty, Celeste Merino, Michelle Souter, Yiwen Zhu, and Orheta Rice in the data collection and/or task development. The report does not necessarily reflect the views of the U.S. Department of Education or the school districts who participated in this project.

* Correspondence concerning this article should be addressed to H. Lee Swanson, Ph.D., Area of Educational Psychology, GSOE, Sproul Hall, University of California-Riverside, Riverside, CA 92521, United States. Contact: Lee.Swanson@UCR.EDU.

control its execution (e.g., ignore the irrelevant information). Given the multistep nature of word problems, WM plays a major role in solution accuracy. Working memory is defined as a processing resource of limited capacity, involved in the preservation of information while simultaneously processing the same, or other, information (e.g., Baddeley, 2012; Engle, Tuholski, Laughlin, & Conway, 1999; Unsworth, 2010).

Although WM is a fundamental component of children's success in solving mathematical problems (e.g., LeBlanc & Weber-Russell, 1996), and underlies math difficulties (MD; Geary, 2010, 2013; Swanson, Jerman, & Zheng, 2008), few intervention studies have been explicitly developed to compensate for individual differences in WM in children with MD. Of those interventions directed at remediating problem solving deficits in children with MD, most focus on general or heuristic procedures (see Gersten et al., 2009; Zheng, Flynn, & Swanson, 2013, for a meta-analysis of these findings). For example, one approach emphasizes the execution of action sequences to solve a problem (e.g., Montague, Krawec, Enders, & Dietz, 2014; Rosenzweig, Krawec, & Montague, 2011). That is, when confronted with a word problem, children are taught a general-heuristic to identify what information is needed within the text (e.g., Brissiaud & Sander, 2010; Hayes, Waterman, & Robinson, 1977), as well as what information is irrelevant to solve the problem (Low & Over, 1989). This cuing of children's attention to text information, such as cues to underline the question sentence, is assumed to facilitate integrating information into a coherent problem representation (referred to in the literature as a situation model). These steps are not necessarily tied to specific types of problems, and therefore are assumed to have some generalizability. The advantages of these procedures, when applied to children with MD, have been attributed to facilitating meta-cognitive skills (e.g., Rosenzweig et al., 2011).

Another approach emphasizes visual-schematic representations (e.g., Jitendra, Star, Rodriguez, Lindell, & Someki, 2011; Van Garderen, 2007). This approach teaches children to integrate solution relevant text elements into a coherent visualization of the word problem (e.g., Van Garderen, 2007). Such procedures draw upon retrieval, retention, and transformation of visual information within a spatial context (Hegarty & Kozhevnikov, 1999). Additional strategies implemented have included combined elements of each approach. Strategies that combine visual and verbal information has been shown to be effective in achievement outcomes (e.g., see Mayer, 2005, for review), mainly because it is assumed the combination of strategies draws upon separate verbal and visual-spatial storage capacities, and by combining these storage systems, more information can be processed (Mayer, 2005).

Current work (Swanson, 2014; Swanson, Lussier, & Orosco, 2013) has shown that while changes in problem-solving accuracy occur as a function of the aforementioned strategy training relative to control conditions, post-test performance favors children with higher WMC over children with lower WMC. These authors argued the advantages for children with higher WMC occurred because strategies rely on declarative representations and serial cognitive processes that require large amounts of WMC, and the utilization of cognitive strategies that have been recently acquired impose high demands on children with lower WMC. These findings are not consistent, however, with intervention studies with adults (e.g., Turley-Ames & Whitfield, 2003) or children (e.g., Fuchs et al., 2014) which suggest that strategy training compensates for demands placed on the limited resources of participants with low WMC. Thus, any particular advantage related to strategy instruction for those children who perform poorly in math as well as suffer WM deficits needs further investigation.

Our previous work on strategy training and the role of WMC in children with MD has two limitations. First, the effects of strategy instruction that involved controlled attention training have not been separated from general heuristic training. That is, the strategy interventions (general strategies or heuristics in this case) in these previous studies (Swanson, 2014; Swanson et al., 2013) were coupled with practice solving word problems that systematically increased interference. Interference occurred by interjecting an increasing number of irrelevant propositions within the word problems that did not contribute to the word problem solution. Thus, any disadvantages for children with low WMC related to strategy training may have been related to the additional burden on children's mental resources related to the controlled attentional training.

Second, the analysis of treatment effects included children who did not suffer from MD. Because children with MD have consistently yielded lower WM scores than children without MD (e.g., Geary, 2013; Swanson & Beebe-Frankenberger, 2004), the potential contributions of individual differences in WMC to treatment outcomes as a function of strategy training may have been confounded by low math performance. Thus, the effects of WMC on cognitive strategy outcomes need to be studied within low math ability groups.

As an extension of this earlier work, the present study further determines the role of WM on strategy outcomes for children with MD who vary in WMC. Of interest was how WMC would impact strategy outcomes for children with MD. To this end, children with MD were randomly assigned to aforementioned general strategy conditions (verbal, visual and combination of verbal + visual heuristics) or a specific strategy that focused only on control attention training.[1] Evaluating such children's performance related to these conditions will address three questions not considered in the earlier studies:

[1] It is important to note that the labels assigned to the three heuristic conditions (verbal emphasis, visual emphasis and verbal + verbal combination) were related to what was emphasized (e.g., diagrams were utilized in the visual condition on the assumption they were creating an external problem representation), and therefore it is important to note that elements of both verbal and visual information occur in all the conditions. We refer to the verbal emphasis, visual emphasis and verbal + visual condition as including heuristics or general strategies since these procedures involved a sequence of steps related to *integrating* information into a coherent representation (via mental model or diagrams) and these procedures can be applied across an array of tasks (reading comprehension, word problems).
All treatment conditions in this study included training materials that focused on identifying inferring information (controlled attention training for irrelevant propositions) within word problems. The specific strategy condition (referred to as materials only-MOC) included on the training materials and did not teach children the verbal and/or visual heuristics.