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The role of literacy skills in adolescents' mathematics word problem performance: Controlling for visuo-spatial ability and mathematics anxiety

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ABSTRACT

The aim of the present study is to examine the relationship between eighth-grade adolescents' literacy skills and mathematics word problem performance. Moreover, visuo-spatial ability and mathematics anxiety were considered as covariates. According to the analyses of (co)variance, literacy skills were significantly associated with mathematics word problem skills among the 99 8th grade participants of the study. It is primarily for boys that reading comprehension skill predicts success in solving math word problems, while technical reading predicts both calculation skill and word problem solving skill across genders. Visuo-spatial ability was not a significant covariate in either of the models, whereas mathematics anxiety was a significant covariate in the girls' model. The results of the present study thus suggest that learning mathematics is particularly intertwined with good technical reading skills, even in adolescence. Additionally, emphasizing an encouraging atmosphere in math classes could help girls with high levels of mathematics anxiety.

1. Introduction

Arithmetic word problems constitute an important part of mathematics in elementary school (Fuchs et al., 2006). One of the most important aims is to integrate formal school mathematics with the real world and to provide an opportunity to apply the learned formal content (Verschaffel, De Corte, & Lasure, 1994; Verschaffel, Greer, & De Corte, 2000). However, despite good intentions school children at varying ages often find these word problems difficult and their performance is not as good as it should be (Verschaffel & De Corte, 1993).

Because of this aforementioned tendency, researchers have been inspired to investigate both individual cognitive abilities and environmental factors that might constrain the development of word problem solving skills and influence access to sophisticated word problem solving strategies (e.g. Rosales, Vicente, Chamoso, Muñez, & Orrantia, 2012; Zheng, Swanson, & Marcoulides, 2011). In addition to effortless calculation ability, good literacy skills (e.g. reading and reading comprehension) are also crucial when solving mathematical word problems presented in written form. There is a growing body of research literature showing a strong interrelation between literacy skills and mathematics word problem solving skills (e.g. Lee, Ng, Ng, & Lim, 2004; Pimperton & Nation, 2010; Roe & Taube, 2006; Vilenius-Tuohimaa, Aunola, & Nurmi, 2008). However, most of the studies have focused on primary school children, whereas the role of literacy skills in adolescent word problem solving is, to date, largely unexplored. In this study, we investigate the power of literacy skills in predicting adolescents' mathematics word problem solving skills along with two other important factors often observed to explain mathematical performance, that is, visuo-spatial ability and mathematics anxiety. Further, the roles of aforementioned factors are investigated in terms of gender differences.

Arithmetic word problems are presented either orally (e.g. Carpenter, Ansell, & Fennema, 1993; Fuchs et al., 2012; Riley & Greeno, 1988) or in written form (e.g. Fuchs et al., 2012; Verschaffel, De Corte, & Vierstrate, 1999). Word problems presented in written form place significant demands on reading comprehension and other literacy skills, such as vocabulary. To be able to solve word problems that require numerical processing, a person has to know the meaning of individual words and also possess the skills to integrate the meanings of these words into semantically more complex meanings (e.g., Kintsch & Greeno, 1985). Moreover, it is essential to identify the problem type in order to activate the existing mathematical knowledge structures (Pape, 2004). Hence, one has to have both linguistic and mathematical knowledge, and one has to be able to flexibly operate between these different knowledge types to be able to solve mathematical word problems. In the present study, the test used for mathematics word problem performance included several types of word problems.

To comprehend word problems in written form, one has to be able to read and understand the text that describes the task. Indeed, the results of the previous studies have shown that during the primary school years, reading fluency significantly predicts performance in solving mathematical word problems (Fuchs et al., 2006; Vilenius-Tuohimaa

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et al., 2008). Moreover, there is evidence suggesting that children often make mistakes in word problems because they do not fully comprehend the verbal instructions (Cummins, Kintsch, Reusser, & Weimer, 1988). One possible reason for this is insufficient language skills (Pape, 2004). Quite recently, it has been suggested that the natural language of word problems might also be an advantage in favor of word problems when compared with number problems (Newman, Willoughby, & Pruce, 2011). If a student has average language skills, he or she can benefit from the text which makes it easier to use context and prior knowledge to support the problem solving process.

Even though text comprehension is essential, other skills are needed as well. First of all, as suggested by Kintsch and van Dijk (1978), the reading comprehension process involves the construction of a mental representation based on the text. The creation and maintenance of at least two kinds of mental models are required for a successful word problem solving process (Hegarty, Mayer, & Monk, 1995; Moreau & Coquin-Viennot, 2003; Rosales et al., 2012; Verschaffel et al., 2000). To begin with, a qualitative situational mental model based on the situation described in the current word problem is formed. In addition to the situational model, a quantitative mathematical model based on the mathematical structure of the word problem is constructed, and it has to fit the situational model. In constructing both models, it is important to differentiate between relevant and irrelevant information. Finally, with the help of these models, the problem can be solved — presuming that the solver has adequate skills to perform the required mathematical algorithms (Rosales et al., 2012).

According to Jonassen (2003), the situational model that is based on the situation described in the task is primarily visual. Hence, visuo-spatial abilities are needed in both constructing this mental representation as well as in maintaining and processing it during the problem solving process. This notion is supported by study results showing that inferior problem-solvers tend to have deficiencies in visuo-spatial working memory (Passolunghi & Mammarella, 2010, 2012) which is argued to be responsible for maintaining and processing visuo-spatial mental representations. Moreover, previous studies concerning young children have proposed that arithmetic word problem solving is based on visuo-spatial mental models of the central features of the tasks (Rasmussen & Bisanz, 2005). It has been quite convincingly shown that visuo-spatial abilities play an important role in word problem solving in preschool and primary school mathematics.

However, less is known about the significance of visuo-spatial abilities in adolescents' word problem solving. Some researchers have suggested that with regard to mathematics in general, in relation to age, verbal skills become more important than visuo-spatial ability (Andersson & Lyxell, 2007; McKenzie, Bull, & Gray, 2003; Rasmussen & Bisanz, 2005). On the other hand, Casey, Nuttall, Pezaris, and Benbow (1995) as well as Casey, Nuttall, and Pezaris (1997) observed that spatial ability predicts adolescents' performance in mathematics. Unfortunately, as in most of the studies concerning adolescents, they used composite scores of mathematics skills to reflect a variety of mathematical sub-skills. Therefore, it is not possible to make conclusions about the role of visuo-spatial abilities in word problem solving based on these aforementioned studies. Kyttälä and Lehto (2008) observed that the word problem solving performance of adolescents is predicted by spatial working memory, which indicates that as with preschool and primary school children, visuo-spatial ability might also play a role in adolescents' word problem solving processes. In this study, visuo-spatial ability is treated as a covariate when predicting word problem performance using literacy skills as an indicator. Because it is possible that the significance of visuo-spatial ability in word problem solving may vary as a function of gender, potential gender differences are also considered in the study. Casey et al. (1995) observed the relationship between spatial ability and mathematics being stronger among girls than among boys. Results supporting this factor of dependence on visuo-spatial ability among girls have later been achieved by Laski, Casey, Yu, Dulaney, Heyman, and Dearing (2013). They observed that first-grader girls with better spatial abilities use higher-level mental strategies more frequently in solving arithmetic problems.

At this point, it is important to note that instead of using the aforementioned more advanced and effective strategy based on mental models, many students solve arithmetic word problems quite superficially by selecting certain key numbers and keywords from the problem as hints (Hegarty et al., 1995). Hegarty et al. (1995) call this "a direct-translation strategy" and state that this strategy is characteristic to unsuccessful problem-solvers. Instead of forming mental models of the task at hand, they simply select some single words from the text, such as *more* or *less*, and base their calculation process on these words regardless of the context and without really concentrating on the task. This often leads to flawed solutions and outcomes.

There are several potential reasons for choosing this superficial strategy. One of them is that students simply do not master adequate word problem solving strategies. Previous studies have shown that students can learn deeper approaches if they are sufficiently instructed (Fuson & Willis, 1989; Jitendra et al., 1998; Xin, Jitendra, & Deatline-Buchman, 2005). Thus, problem solving strategies can be taught and learned. Another potential reason for choosing the superficial strategy is that the students may not have sufficient supporting competencies, such as reading comprehension, visuo-spatial abilities and working memory, to construct and maintain situational and mathematical models.

The third potential reason for superficial performance is task-avoidance, which is often linked to mathematics anxiety, which in turn refers to a state of discomfort, such as fear, tension or distress that occurs when a student is performing mathematical tasks or when he or she is otherwise faced with mathematics. Students that are mathematically anxious tend to avoid the unpleasantness of mathematics by rushing through the tasks. Regardless of high error rates, they work through difficult problems quickly and without concentrating on them (Faust, Aschcraft, & Fleck, 1996). Word problems are often considered difficult (Verschaffel & De Corte, 1993), which is why it is probable that students with mathematics anxiety feel distress when confronting word problems. There is a large body of research suggesting that mathematics anxiety may have a negative effect on mathematics performance (e.g. Ashcraft, 2002; Beilock, 2008; Hembree, 1990; Vukovic, Kieffer, Bailey, & Harari, 2012). It has been suggested that anxiety causes both short-term effects by restricting information processing resources available (Eysenck, Derakshan, Santos, & Calvo, 2007) and by causing task-avoidance as well as long-term effects by causing overall avoidance of a certain field (i.e. mathematics; Faust et al., 1996). In this study, mathematics anxiety was treated as a covariate when predicting word problem performance with literacy skills. Since girls seem to display higher mathematics anxiety levels than boys (Björn & Kyttälä , 2011; Casey et al., 1997; Hembree, 1990; Ma & Cartwright, 2003; Osborne, 2001), and since it has been observed that mathematics anxiety is more stable across time for girls than for boys (Ma & Xu, 2004), potential gender differences are investigated in this study, as well.

1.1. Current study

Although there is a growing body of literature tapping into the relationship between literacy skills and mathematics word problem skills (Roe & Taube, 2006; Vilenius-Tuohimaa et al., 2008), most of these studies have concentrated on primary school children, not adolescents. The same is also true for previous studies including the role of visuo-spatial abilities in word problem solving. Moreover, despite previous research literature having shown strong domain-specific emotions towards mathematics learning (Ashcraft, 2002; Beilock, 2008; Hembree, 1990), the potential effect of mathematics anxiety on word problem solving has nevertheless been taken into account in rather few prior publications. In one of them, Vukovic et al. (2012) reported that among