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

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ARTICLE INFO

Article history:
Received 2 December 2012
Received in revised form 28 August 2013
Accepted 12 October 2013

Keywords:
Adolescents
Literacy skills
Mathematics word problems
Visuo-spatial ability
Mathematics anxiety

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.

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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...
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, & Price, 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 & Mammiarella, 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. Kyttilä 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, Ashcraft, & 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 & Kyttilä , 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
young children mathematics anxiety was negatively related (r = −.36) to mathematical applications (including numeric word problems).

To further investigate factors behind adolescent word problem solving process, the aim of the present study is to examine the relationship between adolescents' literacy skills (technical reading skills, reading comprehension) and word problem solving with and without controlling for visuo-spatial skills and mathematics anxiety. The roles of technical reading and reading comprehension have been studied separately, due to the recent results by Harlaar, Kovas, Dale, Petrill, and Plomin (2012) showing that word decoding and reading comprehension are differently connected to mathematical performance. The mental rotation skill of three-dimensional objects in a two-dimensional space is selected as an indicator of visuo-spatial ability in the present study. Mental rotation skills have been found to be related to mathematics performance (see Laski et al., 2012), but their role in adolescent word problem solving is not clear.

In this study, we aim to answer the following research questions:

1. How are literacy skills (technical reading skills and reading comprehension) related to word problem solving among eighth-graders? It is hypothesized that technical reading and reading comprehension predict word problem solving performance for both girls and boys (see e.g. Roe & Taube, 2006; Vilenius-Tuohimaa et al., 2008). In order to further examine the role of literacy skills in word problem solving, the association between literacy skills and overall calculation skills (not word problems) will also be investigated.

2. How are literacy skills related to word problem solving when visuo-spatial ability is controlled for? Considering that the role of visuo-spatial abilities is suggested to be minor among boys (see e.g. Casey et al., 1995; Laski et al., 2012), it is hypothesized that visuo-spatial ability is a more powerful predictor of word problem solving among girls, and that literacy skills are a more powerful predictor among boys.

3. How are literacy skills related to word problem solving when mathematics anxiety is controlled for? Based on strong evidence suggesting that mathematics anxiety may have a negative effect on mathematics performance (Ashcraft, 2002; Beilock, 2008; Hembree, 1990) and that girls seem to display higher mathematics anxiety levels than boys (Casey et al., 1997; Hembree, 1990; Ma & Cartwright, 2003; Osborne, 2001), we hypothesize that among girls, mathematics anxiety plays a more important role in word problem solving performance than among boys.

2. Method

2.1. Participants

The present data were drawn from the MASA-project (Mathematical learning difficulties and Sociocultural factors among Finnish Adolescents; see Kyttilä, & Björn, 2010; Björn, & Kyttilä, 2011), which explores the possible factors behind mathematics skills differences among Finnish adolescents. Altogether 225 participants joined the MASA-study at the beginning of their 8th grade. Ninety-nine of them (N = 99) took part in this part of the study. This was a random sample consisting of students representing a variety of levels in the measured skills. There was some attrition depending on the students’ availability during the testing sessions. Therefore, the sample size varied from 67 to 99 between the tests. The age distribution of the participants was between thirteen and fourteen years (birth year 1991) as the formal schooling (grade 1) in Finland starts on the year the child turns seven. All the participants came from the city of Helsinki. The sample was homogeneous in terms of ethnic and cultural background and all the participants spoke Finnish as their native language.

2.2. Measures

2.2.1. Calculation ability and mathematical word problem solving skills

The group-administered, KITLT-counting skills test for 7th to 9th graders (Räsänen & Leino, 2005) has four parallel versions (A–D) for follow-up purposes. Version A was used in this particular study. The test consists of sixteen basic calculation and equation tasks (e.g. 'Count 5.01 + 6.7='). Twenty-four of the 40 tasks are word problems (e.g. 'New curtains will be purchased for the school. There are six classrooms with 3 windows in each. There should be 2 curtains in every window. How many curtains will be needed altogether?'). More precisely, the word problems represent different types of word problems: in addition to numerical problems, there are measurement tasks and geometry tasks included. One point is given for each correct answer. The test was given a time limit of 40 min.

In order to investigate the coherence of the mathematics word problem items used in the present study, a hierarchical cluster analysis with the nearest neighbor method is applied. Hierarchical cluster analysis also works as a means to find possible multivariate outliers (items in this case) from the data. Based on cluster analysis, four of the 24 items were omitted from the sum variable ‘Mathematical Word Problems’, because they formed three clusters that did not belong to any other item cluster. Consequently, the final maximum sum score for the test was 20. The internal reliability of both the A-version and the C-version in the normative data (N = 1157) was .88 (Räsänen & Leino, 2005). The test also correlated significantly with other measures of mathematical skills (r = .61–.78, p < .001; Räsänen & Leino, 2005).

2.2.2. Literacy skills

a. Technical reading skills are measured as a combination of the following two tasks from a Dyslexia screening test for adolescents and adults (Holopainen, Kairaluoma, Nevala, Ahonen, & Aro, 2004). The first one is find the spelling errors. In the task, the participant is supposed to find an extra letter, missing letter or a wrong letter from a word and to mark it. The second task is separate the words in which the participant is instructed to draw lines between understandable words in a word chain as fast as possible (e.g. kilpakohtiparialla [racetowardspairunder]: kilpa/kohti/pari/alla [race/towards/pair/under]). The maximum score for each of the tasks is 100 totaling as maximum score of 200. The time limit for each of the sub-tests is 3 min and 30 s. The two sub-test scores were further combined to form a variable “Technical reading skills”. Test–retest reliability for the spelling error task is reported as .83 and for the separate word task as .84 (Holopainen et al., 2004).

b. Reading comprehension is measured using a subtest from a Dyslexia screening test for adolescents and adults (Holopainen et al., 2004). The participants read a story called the Hounds of the Village. There are 52 words that have been changed so that they do not fit to the story. The participant is supposed to find these inappropriate words and underline them. A point is given for each correctly underlined word. The time limit for this particular sub-test is 45 min. Cronbach’s alpha for this sub-test is .91.

2.2.2.1. Visuo-spatial ability. The mental rotation task is based on figures originally devised by Shepard and Metzler (1971) and it is inspired by the group-test developed by Vandenberg and Kuse (1978). In the rotation task, participants are presented with abstract two-dimensional projections of three-dimensional figures using an overhead projector. Each transparency consists of one stimulus figure and four other figures, two correct and two incorrect alternatives. Both correct alternatives are identical to the stimulus but they are rotated into different positions. The two incorrect alternatives are rotated mirror images of the stimulus. The time that each transparency is shown is 30 s. During that time, the participants are supposed to identify the correct alternatives and mark them down on their answer sheets. Twelve different trials are presented. One point is given for each two correctly chosen alternatives. That is,
participants are supposed to identify both correct alternatives to get one point. This was required to diminish the possibility to get points just by guessing. The maximum score is 12. The split-half reliability for the task is .83.

2.2.2.2. Mathematics anxiety. Mathematics anxiety is measured with the mathematics anxiety rating scale (MARS; Suinn, 1988). In MARS, participants rate themselves on a five-point scale on the level of anxiety they would feel in various mathematics-related situations in both school and everyday life. In the Finnish version, there are 89 items. The maximum score is 445. Cronbach’s alpha for this sample is .98.

3. Results

3.1. Associations between literacy skills, mathematics word problem solving skills, visuo-spatial ability and mathematics anxiety

In Table 1, the raw score means and standard deviations with Cohen’s d:s for gender comparisons are presented. To examine the associations between the main variables in the present study, a set of Pearson product-moment correlations were first calculated using the z-scores of each variable (see Table 2 for the correlation coefficients). Inspection of the correlations showed that overall, both technical reading and reading comprehension were strongly associated with mathematics word problem skills, whereas there were no interrelations between the measures for literacy skills, visuo-spatial ability and mathematics anxiety. However, there was a statistically significant association between mathematics anxiety and mathematics word problem skills (r = −0.25, p < 0.05) indicating that those participants that reported higher levels of mathematics anxiety performed worse in mathematics word problems than others. Calculation ability was interrelated with technical reading skills and, expectedly, with mathematics word problems.

As to the gender-specific associations between the skills mentioned above, there were significant associations between technical reading and mathematics word problem performance, reading comprehension and mathematics word problem performance and between calculation ability and mathematics word problem performance in the boys’ matrix, respectively. There were also similar associations in the girls’ matrix between these skills, except that in the girls’ matrix there was also a significant relationship between technical reading and calculation ability. Additionally, there was a statistically significant association in the girls’ matrix between mathematics anxiety and mathematics word problem skills (r = −0.36, p < 0.05) suggesting that the higher the level of mathematics anxiety reported, the poorer the performance in mathematics word problems. It is also noteworthy that there was a nearly statistically significant interrelation in the girls’ matrix between mathematics anxiety and visuo-spatial ability (r = 0.38, p = 0.09).

3.1.1. Analysis steps

First, technical reading and text comprehension sum variables were dichotomized for ANOVAs. After careful inspection of the distributions, Group 1 in Technical reading (33.3% of the participants) consisted of participants having scores ranging from 19 to 91 and Group 2 had scores ranging 92–178. Group 1 in text comprehension (33.3%) consisted of participants having scores ranging from 1 to 24 and Group 2 had scores ranging 25–45, respectively. Next, all the main variables were reversed into z-scores. They then represented the z-scored order of individual participants in the main study variables (technical reading skills, text comprehension, visuo-spatial ability, calculation skills, mathematics anxiety and mathematics word problem performance). Hence, as ANOVAs and ANCOVAs were used in the analyses, the results actually represent the predicting power of these variables at an individual level. In order to address the research questions, a series of ANOVA and ANCOVA-analyses were applied by, firstly, using all the data and, secondly, by calculating the models separately for girls and boys. The main focus was, firstly, on investigating the interrelationship between literacy skills (technical reading skills and text comprehension) and mathematical word problems. Secondly, this interrelationship was investigated controlling separately for visuo-spatial ability and mathematics anxiety. Thirdly, it was examined whether the (co)variance structures were similar between girls and boys.

The ANOVA–ANCOVA calculation was performed with the following models: Firstly (model 1), technical reading skills and text comprehension were used as predictors of mathematics word problems in the variance analysis model. Secondly (model 2), the possible role of visuo-spatial ability as a covariate was investigated. Regardless of whether it would be a statistically significant covariate, its impact on the interrelationship between literacy skills and mathematics word problem performance would be interpreted. Thirdly (model 3), mathematics anxiety as a covariate was investigated. Regardless of whether it would be a statistically significant covariate, its impact on the interrelationship between literacy skills and mathematics word problem performance would be interpreted.

3.2. The roles of visuo-spatial skills and mathematics anxiety in calculation skills and mathematical word problem performance

The results of variance modeling are displayed in Table 3 for calculation skills as the dependent variable and in Table 4 for mathematical word problem performance as dependent variable. Moreover, adjusted R²:s for each model are shown. Table 3 clearly shows that only technical reading skills are associated with calculation skills. In Table 4, model 1 with the dichotomic technical reading and reading comprehension as independent variables and mathematics word problem skills as dependent variable for “All” confirms the expected result: there is a strong interrelationship between literacy skills and mathematics word problem skills. Visuo-spatial ability was not a significant covariate. Therefore, model 1 was stronger in that sense. After mathematics anxiety was controlled for (F(1) = 4.80, p < 0.05), both technical reading and text comprehension were still strongly related to mathematics word problem skills. The strongest model in terms of the R²:s was the one (model 3) in which mathematics anxiety was held constant (R² = 0.35). It has to be noted, however, that the R² differences between the models may have to do with sample size.

Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>All (n = 67–99)</th>
<th>Girls (n = 32–49)</th>
<th>Boys (n = 32–50)</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N M, SD</td>
<td>N M, SD</td>
<td>N M, SD</td>
<td></td>
</tr>
<tr>
<td>Technical reading</td>
<td>99 (28,71)</td>
<td>103,29, 30,89</td>
<td>81, 41&lt;sup&gt;2&lt;/sup&gt;</td>
<td>111,55, 29,34</td>
</tr>
<tr>
<td>Text comprehension</td>
<td>99 (32,67)</td>
<td>28,37, 9,74</td>
<td>12, 37&lt;sup&gt;2&lt;/sup&gt;</td>
<td>30,31, 9,21</td>
</tr>
<tr>
<td>Calculation skills</td>
<td>99</td>
<td>9,34, 4,05</td>
<td>49</td>
<td>9,66, 4,09</td>
</tr>
<tr>
<td>Mathematical word prob.</td>
<td>99</td>
<td>11,79, 3,38</td>
<td>49</td>
<td>11,47, 3,25</td>
</tr>
<tr>
<td>Visuo-spatial ability</td>
<td>67</td>
<td>5,31, 3,20</td>
<td>35</td>
<td>5,40, 3,21</td>
</tr>
<tr>
<td>Mathematics anxiety</td>
<td>74</td>
<td>53,65, 9,33</td>
<td>32</td>
<td>53,53, 7,66</td>
</tr>
</tbody>
</table>

Note. Cohen’s d: interpretation: 0.20–0.40 small; 0.50–0.70 medium; 0.80–2.0 large.<sup>1</sup> Numerus of the adolescents in the poor readers’ group; <sup>2</sup> Numerus of the adolescents in the good readers’ group, respectively.
with the visuo-spatial ability and mathematics anxiety measures assessed within a subset of fewer participants.

3.3. The gender-specific interplay

Next, the same modeling was carried out separately for girls and boys. First, the girls’ model with technical reading and reading comprehension as independent variables and mathematics word problem skills as dependent variable was tested (model 1). The results showed, that the interrelationship between technical reading and mathematics word problems \((F = 9.96, p < 0.01)\) was statistically significant, whereas the role of reading comprehension was not. Visuo-spatial ability was not a statistically significant covariate. After mathematics anxiety was controlled for, technical reading skills were still interrelated with mathematics word problem skills. However, the strongest model in terms of the \(R^2\)'s was the one with visuo-spatial ability, even though it was not a statistically significant covariate and thus the other results of model 2 will not be interpreted \((R^2 = 0.40)\).

The boys’ model with technical reading and reading comprehension as independent variables and mathematics word problem skills as dependent variable was tested next. The results showed, that both technical reading \((F = 11.83, p < 0.001)\) and text comprehension \((F = 9.30, p < 0.01)\) were significantly associated with mathematics word problems. Visuo-spatial ability and mathematics anxiety were not statistically significant covariates among the boys’ data. However, the strongest model for boys in terms of the \(R^2\)'s was the one in which mathematics anxiety was held constant \((R^2 = 0.38)\).

### Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Technical reading</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.50***</td>
<td>0.51***</td>
<td>0.06</td>
<td>–</td>
<td>–</td>
<td>0.27</td>
<td>0.44***</td>
<td></td>
</tr>
<tr>
<td>2. Text comprehension</td>
<td>0.54***</td>
<td>–</td>
<td>–</td>
<td>0.45***</td>
<td>–</td>
<td>0.48***</td>
<td>–</td>
<td>0.04</td>
<td>–</td>
<td>0.07</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>3. Mathematical word probl.</td>
<td>0.54***</td>
<td>0.50***</td>
<td>–</td>
<td>0.60***</td>
<td>0.57***</td>
<td>–</td>
<td>–</td>
<td>0.07</td>
<td>–</td>
<td>0.36***</td>
<td>0.46***</td>
<td></td>
</tr>
<tr>
<td>4. Visuo-spatial ability</td>
<td>0.09</td>
<td>–</td>
<td>0.02</td>
<td>–</td>
<td>0.03</td>
<td>–</td>
<td>0.12</td>
<td>–</td>
<td>0.02</td>
<td>0.03</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>5. Mathematics anxiety</td>
<td>–</td>
<td>0.18</td>
<td>–</td>
<td>0.09</td>
<td>0.25***</td>
<td>–</td>
<td>0.04</td>
<td>–</td>
<td>0.14</td>
<td>–</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>6. Calculation skills</td>
<td>0.25***</td>
<td>0.14</td>
<td>0.38***</td>
<td>0.08</td>
<td>–</td>
<td>0.11</td>
<td>–</td>
<td>0.26</td>
<td>0.10</td>
<td>0.33</td>
<td>0.09</td>
<td>–</td>
</tr>
</tbody>
</table>

Note 1. \(p < 0.05; \) *** \(p < 0.001\). Note 2. The first correlation matrix is for all participants. The second correlation matrix includes the boys’ correlations below the diagonal and the girls’ correlations above the diagonal, respectively. Note 3. \(p = 0.09\).

### Table 3

ANOVAs and ANCOVAs for calculation skills by literacy skills, controlling for visuo-spatial ability and mathematics anxiety.

<table>
<thead>
<tr>
<th>Variable</th>
<th>All</th>
<th>Girls</th>
<th>Boys</th>
<th>All, girls, boys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 (df1, df2)</td>
<td>(3, 95)</td>
<td>(3, 45)</td>
<td>(3, 46)</td>
<td>0.17, 0.24, 0.08</td>
</tr>
<tr>
<td>Technical reading</td>
<td>19.51***</td>
<td>13.95***</td>
<td>6.66***</td>
<td></td>
</tr>
<tr>
<td>Reading comprehension</td>
<td>0.01 ns.</td>
<td>0.16 ns.</td>
<td>0.03ns</td>
<td></td>
</tr>
<tr>
<td>Model 2 (df1, df2)</td>
<td>(3, 62)</td>
<td>(3, 31)</td>
<td>(3, 31)</td>
<td>0.30, 0.43, 0.15</td>
</tr>
<tr>
<td>Visuo-spatial ability (constant)</td>
<td>0.14 ns.</td>
<td>0.02 ns.</td>
<td>0.19 ns.</td>
<td></td>
</tr>
<tr>
<td>Technical reading</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Reading comprehension</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Model 3 (df1, df2)</td>
<td>(3, 69)</td>
<td>(3, 28)</td>
<td>(3, 37)</td>
<td>0.20, 0.19, 0.23</td>
</tr>
<tr>
<td>Mathematics anxiety (constant)</td>
<td>0.84 ns.</td>
<td>0.10 ns.</td>
<td>0.22 ns.</td>
<td></td>
</tr>
<tr>
<td>Technical reading</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Reading comprehension</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

Note. All the reported variance analysis models with and without covariates include the same design with dichotomized independent variables technical reading \(\times\) reading comprehension and dependent continuous variable calculation skills.

### Table 4

ANOVAs and ANCOVAs for mathematics word problem skills by literacy skills, controlling for visuo-spatial ability and mathematics anxiety.

<table>
<thead>
<tr>
<th>Variable</th>
<th>All</th>
<th>Girls</th>
<th>Boys</th>
<th>All, girls, boys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 (df1, df2)</td>
<td>(3, 95)</td>
<td>(3, 45)</td>
<td>(3, 46)</td>
<td>0.27, 0.34, 0.27</td>
</tr>
<tr>
<td>Technical reading</td>
<td>15.78***</td>
<td>9.96***</td>
<td>11.83***</td>
<td></td>
</tr>
<tr>
<td>Reading comprehension</td>
<td>9.27**</td>
<td>0.68</td>
<td>9.30***</td>
<td></td>
</tr>
<tr>
<td>Model 2 (df1, df2)</td>
<td>(3, 62)</td>
<td>(3, 31)</td>
<td>(3, 31)</td>
<td>0.33, 0.40, 0.35</td>
</tr>
<tr>
<td>Visuo-spatial ability (constant)</td>
<td>0.24 ns.</td>
<td>0.61 ns.</td>
<td>0.12 ns.</td>
<td></td>
</tr>
<tr>
<td>Technical reading</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Reading comprehension</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Model 3 (df1, df2)</td>
<td>(3, 69)</td>
<td>(3, 28)</td>
<td>(3, 37)</td>
<td>0.35, 0.37, 0.38</td>
</tr>
<tr>
<td>Mathematics anxiety (constant)</td>
<td>4.80*</td>
<td>5.57**</td>
<td>1.25 ns.</td>
<td></td>
</tr>
<tr>
<td>Technical reading</td>
<td>15.66***</td>
<td>6.32*</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Reading comprehension</td>
<td>7.52***</td>
<td>2.07</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

Note. All the reported variance analysis models with and without covariates include the same design with dichotomized independent variables technical reading \(\times\) reading comprehension and dependent continuous variable mathematics word problem skills.

4. Discussion

The aim of the present study was to examine the relationship between adolescents’ literacy skills (technical reading skills, reading comprehension) and mathematics word problem performance, both with and without controlling for visuo-spatial ability and mathematics anxiety. The anticipated differing patterns between genders were also taken into account.

The results showed that the initial assumption of the association between technical reading and reading comprehension and mathematics word problem skills can be confirmed in the present adolescent sample, as well. This result was in line with e.g. Lee et al. (2004), Pimperton and Nation (2010), Roe and Taube (2006), and Vilenius-Tuohimaa et al. (2008), indicating that literacy skills are important factors in predicting word problem solving performance, not only during primary school years but during adolescent years, too. To compare whether the association between literacy skills and mathematics word problem solving differed from the association between literacy skills and overall calculation skills, separate (co)variance models were calculated. The results show that while both technical reading skills and reading comprehension were related to word problem solving skills, only technical reading skill was associated with the overall calculation skills. This further indicates that among adolescents 1) technical reading skills are important in mathematics in general and 2) that reading comprehension becomes more important while performing mathematical word problems with more complex verbal instructions.

Among the factors investigated in our study, literacy skills were the most powerful predictors of word problem performance. Thus it seems
that reading and understanding the text that describes the task is an essential phase in word problem solving also for adolescents, and that individual differences in literacy skills significantly affect word problem solving performance at adolescent age. Even though earlier research evidence has proven that there is an interrelation between reading comprehension and visuo-spatial abilities especially among young children (De Beni, Pazzaglia, Gyselinck, & Meneghetti, 2005; Jonassen, 2003; Rasmussen & Bisanz, 2005), in our adolescent data visuo-spatial abilities measured with mental rotation tasks were not associated with word problem performance. In fact, our results are in line with the previous studies concerning overall mathematics skills suggesting that verbal skills become more important than visuo-spatial ability in mathematics as age increases (Andersson & Lyxell, 2007; McKenzie et al., 2003; Rasmussen & Bisanz, 2005). On the other hand, our results contradict with the results of e.g. Casey et al. (1995, 1997) as well as Geary, Saults, Liu, and Hoard (2000), who observed that mental rotation performance predicts adolescents’ performance in mathematics. However, there are certain issues that should be taken into account while comparing our results with theirs. First of all, as in many of the studies concerning adolescents, Casey et al. (1995, 1997) used composite scores of mathematics skills to reflect a variety of mathematical sub-skills. Therefore, it is not possible to draw conclusions about the role of visuo-spatial abilities in word problem solving based on their studies. Furthermore, in the study of Geary et al. (2000), participants were older (M(age_sample1) = 19 and M(age_sample2) 18.5) than in our study, and they were university students which makes the sample more selected than ours. In Finland, the entire age cohort is represented in the 8th grade. In other words, no educational selection has taken place yet.

Mathematics anxiety was significantly and negatively associated with word problem performance, indicating that those adolescents with higher anxiety levels showed poorer performance in mathematics word problems. Like many previous studies (e.g. Ashcraft, 2002; Beilock, 2008; Hembree, 1990; Vukovic et al., 2012) that have been shown, mathematics anxiety tends to have a negative effect on mathematics performance, possibly by restricting available information processing resources (Eysenck et al., 2007) or by causing task-avoidance (Faust et al., 1996). Presumably, as stated before, anxiety might play an even more important role in word problem solving since word problems are often considered difficult (Verschaffel & De Corte, 1993). However, despite mathematics anxiety being negatively related to word problem performance, both technical reading and reading comprehension were still strongly related to mathematics word problem skills after mathematics anxiety was controlled for.

The next goal was to investigate the same model structure separately for girls and boys. Our results suggest that the factors that are associated with word problem solving performance vary among girls and boys. Firstly, the girls’ model with technical reading and reading comprehension as independent variables and mathematics word problem skills as the dependent variable was tested. The results showed that girls had higher performance in technical reading and reading comprehension than boys. However, the girls with a higher level of reading comprehension skills did not necessarily manage well in the mathematics word problems. The results showed, that the interrelationship between technical reading and mathematics word problems was statistically significant, whereas the role of reading comprehension was not, which suggests that there are other more important factors explaining female adolescents’ word problem performance than reading comprehension.

In light of previous research, one of those more important factors might have been visuo-spatial ability. However, in our adolescent female data visuo-spatial ability measured with mental rotation tasks was not related to word problem performance. Another potential factor which was a more important predictor than reading comprehension was mathematics anxiety. Mathematics anxiety turned out to be significantly and negatively related to word problem performance among adolescent females supporting previous results suggesting that mathematics anxiety (see, e.g., Ashcraft, 2002; Beilock, 2008; Hembree, 1990; Vukovic et al., 2012) has a negative effect on mathematics performance. It is probable that girls that show mathematics anxiety rush through the tasks in order to avoid the unpleasantness of word problems as also suggested by Faust et al. (1996). However, the results of the present study indicated that after mathematics anxiety was controlled for, technical reading skills were still interrelated with mathematics word problem skills, suggesting that technical reading skills have a unique role in mathematical word problem performance.

The boys’ model with technical reading and text comprehension as independent variables and mathematics word problem skills as dependent variable was tested. The results showed that the role of both technical reading and text comprehension in mathematics word problems was strong. This result suggests that the basic assumption of good literacy skills also helping in high mathematics word problems performance (see e.g. Lee et al., 2004; Pimperton & Nation, 2010; Roe & Taube, 2006; Vilienius-Tuohimaa et al., 2008) was true for boys. Among the factors investigated in our study, literacy skills were the only factors associated with word problem performance. Based on these results, it seems that the way boys approach mathematics word problems is mainly affected by fluent literacy skills (technical reading and reading comprehension). Neither visuo-spatial abilities nor mathematics anxiety were significant covariates, which indicates that they were not related to mathematics word problem performance.

In conclusion, for both boys and girls, technical reading predicts both calculation skills and word math problem success. This finding is supported by previous research, showing that phonological deficits are related to mathematical difficulties, for example difficulties in arithmetic fact retrieval (Boets & De Smedt, 2010; De Smedt, Taylor, Archibald, & Ansari, 2010). Arithmetic fact retrieval can be considered to be an important part of both basic calculation and word problem solving. However, reading comprehension skills predict only boys’ performance in solving math word problems. Consequently, poor reading comprehension skills may be a problem for boys when solving word problems and on the other hand, they might benefit from good reading comprehension skills in word problems solving situations. Based on our data, interventions targeting at improving boys’ word problem solving performance should be focused on rearing their reading comprehension skills and literacy skills in general. Girls, on the contrary, do not necessarily benefit from their good reading comprehension skills while solving word problems. Girls in our data had significantly better reading comprehension skills than boys, but performed slightly more poorly on the math word problems. Instead of reading comprehension, mathematics anxiety was significantly and negatively related to girls’ word problem performance.

These gender-specific results support previous evidence showing that mathematics anxiety is more problematic to girls (Casey et al., 1997; Hembree, 1990; Ma & Cartwright, 2003; Kytäla & Björn, 2010; Osborne, 2001). However, it is notable that contradictory to many aforementioned studies, when comparing means of mathematics anxiety, there were no gender differences. That is, girls and boys reported feeling equally anxious about mathematics. Based on our data, adolescent girls might benefit from interventions aimed at diminishing anxiety in mathematics word problem situations. In such interventions, it should be important to intervene with the entire learning environment, considering that classroom atmosphere, instructions and experiences in case of failure are all related to the individual experiences of academic emotions, such as anxiety (Frenzel, Pekrun, & Goetz, 2007). Visuo-spatial abilities measured with mental rotation tasks were not significantly associated with word problem performance either among boys or girls. Neither was there a gender difference in mental rotation performance even though many previous studies have shown that males often outperform females in this type of tasks, especially during the adolescent years (Neuberger, Jansen, Heil, & Quaiser-Pohl, 2011; Titze, Jansen, & Heil, 2010). Thus, compared to
many other studies, girls and boys in our data were more equal in terms of the level of literacy and visuo-spatial abilities.

4.1. Limitations of the study

As to the interpretations of the results of our study, it should be taken into account that our set of potential antecedents of adolescents' mathematical word problem solving performance was limited. Thus, interpretations concerning the importance of different factors explaining adolescent word problem performance can only be made in relation to the factors measured in our study. For example, measures of WM, fluid intelligence or processing time, which are often observed to relate to mathematical performance and also to word problem performance (e.g. Kytälä & Lehto, 2008; Passolunghi & Mammarella, 2010, 2012; Pellegrino & Goldman, 1987), were not included in our study. In the future, the role of literacy skills, visuo-spatial ability and mathematics anxiety should be studied in line with other factors often considered to be related to mathematical performance. Another limitation in our study was the fairly small sample (N = 99). In addition to the small sample, the ANOVAs that included dichotomizing the reading measures into high and low functioning students may have produced more limited results than using more conventional methods such as regression analysis. Thus, in the future, replication studies should be conducted as well as varying analysis methods applied to verify the results presented in this article.

As for the tests used, only mental rotation ability was now used as a measure of visuo-spatial ability. As suggested by Meneghetti, De Beni, Pazzaglia, and Gyselinck (2011), rotation tasks only measure the ability to manipulate mental representations which is a narrow aspect of visuo-spatial abilities. This might be the main reason for null results in that part. Further, there were many types of mathematics problems included in the standardized test that was used in this study. However, as previous literature has shown differing patterns of relationships between the cognitive measures, literacy skills and mathematics word problem performance emerge depending on the mathematics domain (Delgado & Priedo, 2004).

In future research, it would be important to be able to use different types of mathematics word problems and to find out whether the patterns of relationships differ between genders. Furthermore, in the sense of analysis possibilities it would have been interesting to investigate whether visuo-spatial ability and mathematics anxiety are true mediators in the interrelationship between literacy skills (technical reading skills and reading comprehension) and mathematical word problems. For example, a series of critical statistical tests for mediators as proposed by Rosenthal (1988) could have been used. However, the approach suggested by Rosenthal (1988) would have required us to hypothesize that either the visuo-spatial ability or mathematics anxiety, or both of them together might be even more powerful predictors of mathematics word problem skills than the literacy skills variables (technical reading and text comprehension). In other words, whether a variable is considered either as a mediator or a covariate, its role in relation to the independent variables and dependent variables is different. In the present study the roles of visuo-spatial ability and mathematics anxiety were investigated as covariates, not mediators, respectively.

5. Conclusions

The current study adds to the existing body of literature by showing that strong linkages between literacy skills and mathematics word problem solving skills exist also among adolescents. The role of literacy skills in mathematics word problem performance seems to be more important among boys than among girls. Technical reading skills are related to both girls' and boys' math word problem performance, but reading comprehension skills are only related to boys' word problem performance. Among the factors investigated in our study, literacy skills were the only factors associated with boys' word problem performance. As suggested by Van Keer and Verhaeghe (2005) fluent technical reading enhances the capacity to work with more difficult issues in e.g. problem solving situations. If one does not have to concentrate on mechanical reading process, one has more information processing resources to aim at the more demanding parts of the task. First of all, as to the role of fluent reading skills in word problem solving, it is important to confirm that those students with poorer literacy skills also have enough time to complete word problem tasks. In light of mathematics anxiety being a significant factor in explaining word problem performance among adolescent girls, more emphasis should be placed to the math class atmosphere. Mathematics word problems should be nothing to be afraid of. In fact, by offering a context and connection to prior knowledge, the text might make word problems even easier than plain number problems (see Newman et al., 2011).

References


