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IS READING COMPREHENSION ASSOCIATED WITH MATHEMATICS SKILLS: A META-ANALYSIS RESEARCH

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Abstract

The literature on the association between reading comprehension and mathematics skills is complicated and conflicting. This study seeks to illuminate the nature of the association between mathematics skills and reading comprehension by incorporating potential moderators, namely components of mathematics skills, domains of content standards in mathematics, age, language status, and developmental issues. The dataset for this study included 49 studies with 91 correlation coefficients representing 37.654 participants. The findings obtained in this study showed that reading comprehension had a significantly strong effect on students' mathematics skills. This association was moderated by components of mathematics skills, domains of content standards in mathematics, age, language status, and developmental issues. Moderation analyses revealed that problem-solving was the strongest moderator of the association between reading comprehension and mathematics skills, whereas spatial skills were the weakest moderator of this relationship. Based on domains of content standards in mathematics, geometry was the weakest moderator of the association between mathematics skills and reading comprehension. Moreover, the effects of reading comprehension on students' mathematics skills significantly differed in favor of elementary students, students with learning disabilities, and second language learners. Therefore, this research can shed light on the literature by synthesizing the effects of reading comprehension on students' mathematics skills.

Keywords: Mathematics skills, reading comprehension, meta-analysis, moderator analysis.

INTRODUCTION

Reading is an indispensable ability for individuals to succeed in real-world situations, as it serves to have an understanding of a topic (Mckee, 2012). Reading ability is vital as it makes the reader appear intellectual, knowledgeable, and sophisticated in daily life. Reading comprehension is one of the prominent components of reading ability. It is defined as the skill of a student to understand printed material (Lin, 2020). Reading comprehension is a mental activity through which an individual selects truths, data, or viewpoints from a written passage. Within this cognitive process of reading comprehension, an individual determines the meanings that the writer intends to convey; determines how they are associated with previous information; and evaluates the suitability and value of that written passage to achieve her own goals (Veeravagu et al., 2010). In reading comprehension, it is not enough to just read the text, but the reader should also be able to break down, analyze, and rearrange thoughts and data in a written passage (Mckee, 2012). Moreover, reading comprehension performance is closely related to the reader characteristics of previous experiences and prior knowledge (Schaffner & Schiefele, 2013). Therefore, reading comprehension is considered a comprehensive and versatile ability that requires readers to have both cognitive and language skills (Lerkkanen et al., 2005).

Reading comprehension is a crucial part of a student's educational development and is a strong predictor of mathematics skills (Mckee, 2012; García-Madruga et al., 2014). Reading comprehension is closely related to mathematics as it is a cognitive skill that supports students' smooth understanding of mathematical concepts and problem-solving (García-Madruga et al., 2014). A student's mathematics skills and learning process in mathematics can be influenced by reading comprehension, which is one of the most important predictors of academic performance (Bullen et al., 2020). There are many studies investigating the association between reading comprehension and mathematics skills. The studies indicate that a significant and positive relationship between reading comprehension and mathematics skills (e.g., Vilenius-Tuohimaa et al., 2008; Boonen et al., 2013; Schaffner & Schiefele, 2013; Bullen et al., 2020). In contrast, the results of several studies showed no statistically significant relationship between reading comprehension and mathematics skills (e.g., Imam et al., 2013; Bullen et al., 2020; Trakulphadetkrai et al., 2020). Although it has been seen that a genetic overlap between reading comprehension and mathematics skills has been reported in the literature, little is still known about the association between mathematics skills and reading comprehension (Vilenius-Tuohimaa et al., 2008; Harlaar et al., 2012). Additionally, the previous studies on the relationship between mathematics skills and reading comprehension are complicated and conflicting. Studies on this topic have indicated ambiguous findings. Up to this point, studies have not provided much insight into how reading comprehension and mathematics skills are related. Therefore, a meta-analysis study investigating the association between reading comprehension and mathematics skills could provide a comprehensive and up-to-date understanding of the correlation between these structures, but the literature does not provide such a meta-analysis study. In conclusion, a study that focuses on the association between mathematics skills and reading comprehension while incorporating potential moderators may provide comprehensive, updated, and valuable findings on this topic.

Potential Moderators in the Context of Mathematics Skills and Reading Comprehension

It is not easy to understand the association between mathematics skills and reading comprehension since mathematics skills are a set of different skills consisting of arithmetic skills, logical reasoning, and spatial skills (Lin, 2011). Arithmetic skills are related to procedural knowledge and the correctness, flexibility, and fluency of arithmetic operations in natural numbers, integers, fractions, decimals, real numbers, percentages, algebra, and calculus (Xie et al., 2020). Logical reasoning covers the comparison, generalization, induction, analysis, and synthesis of real-world situations, rules, and quantitative relationships in the context of mathematics (Lin, 2011). Spatial skills are associated with mental rotation, visualization, spatial memory, spatial orientation, spatial perception, understanding symmetry, translation, and transformation of geometric figures, along with the interpretation of algebraic rules in the context of geometry (Xie et al., 2020). Moreover, the first thing that comes to mind when thinking of mathematical skills is problem-solving because the application of mathematical ideas in the real world and STEM fields can be reflected by problem-solving (Fuchs et al., 2020). Problem-solving has great prominence in each part of the mathematics curriculum and at each grade level from kindergarten to high school (Fuch et al., 2015). Therefore, problem-solving performance is the greatest indicator of mathematics achievement, as students' mathematics skills are generally assessed based on problem-solving tasks (Fuchs et al., 2020).

The greatest predictor of problem-solving is reading comprehension since the first stage of the problem-solving phase requires an individual to comprehend the problem statement and context (Özcan & Doğan, 2018; Pongsakdi et al., 2020). Albert Einstein is the most outstanding scientist of the 20th century and emphasizes, "*If I had an hour to solve a problem, I would spend 55 minutes thinking about the problem and 5 minutes thinking about solutions*." Thus, it is necessary to think carefully and understand the problem situation properly to solve a problem. Several studies results reveal that even students who have strong arithmetical skills, spatial skills, or logical reasoning have difficulty solving real-world problems due to limited reading comprehension and an incorrect understanding of the problem situation (e.g., Bjork & Crane, 2013; Boonen et al., 2014; Özcan & Doğan, 2018; Can, 2020). Most previous studies indicate that reading comprehension has a stronger impact on problem-solving than spatial skills, arithmetic skills, and logical reasoning (e.g., Lee et al., 2004; Hart et al., 2010; Bjork & Crane, 2013; Harlaar et al., 2012; Fuchs et al., 2015; Murrihy et al., 2017; Pongsakdi et al., 2020). For example, a greater relationship between reading comprehension and problem-solving (r = .45) than arithmetic skills (r = .42) and spatial skills (r = .34) among elementary students is reported by Murrihy et al. (2017). Likewise, a strong relationship (r = .60) between problem-solving and reading comprehension and a moderate relationship (r = .49) between reading comprehension and logical reasoning among elementary students are found by Can (2020). However, some studies (e.g., Swanson, 2004; Bullen et al., 2020) show that there is a greater relationship between reading comprehension and arithmetic skills than problem-solving. Moreover, arithmetic skills, spatial skills, logical reasoning, and problem-solving (Harlaar et al., 2012; Cantin et al., 2016; Anselmo et al., 2017; Kikas et al., 2020) showed comparable relationships with reading comprehension. Therefore, the relationship between the components of mathematics skills and reading comprehension remains controversial, and the results of studies in the literature are also inconsistent. Besides, little is known about the association between reading comprehension and the components of mathematics skills.

In the literature, the relationship between reading comprehension and mathematics skills, mathematics achievement is measured by mathematics tasks that span the domain of numbers and operations, the domain of algebra, the domain of geometry, or all domains of the content standards. In particular, the content standard of algebra has its own language, and many students have difficulty learning the language of algebra. Students can solve word problems related to algebra by converting words into the language of algebra (Özcan & Doğan, 2018). Similarly, in the context of solving word problems related to numbers and operations or geometry, students should translate words into numbers or figures. Cummins et al. (1988) have emphasized that correct answers to word problems are associated with strong reading comprehension skills in the context of algebra tasks. Although it can be asserted that reading comprehension has a greater impact on algebra than other content standards, more extensive research to confirm this assertion is needed.

Research has revealed developmental differences in the reading comprehension skills of readers (Chae, 2004). The results of van den Broek's (1997) study indicated that younger students were not as able to use causal relationships and make inferences in the context of the text as older students. Moreover, older students in middle school have reading comprehension skills, especially in the use of causal relations, almost at the same level as adults. However, younger students have less reading comprehension skills in finding causal relationships and making interference in the text than middle and high school students (e.g., Broek, 1997; Chae, 2004). Therefore, reading comprehension may vary depending on an individual's cognitive abilities and age. At this point, age can be considered an important moderator between mathematics skills and reading comprehension. Previous studies indicated that the effects of reading comprehension on students' mathematics skills in elementary school significantly were greater than for middle and high schools (e.g., Björn et al., 2016; Salihu et al., 2018). Given the impact of age on reading comprehension, more extensive studies comparing the relationships between reading comprehension and mathematics skills across age groups may be valuable (Bjork & Crane, 2013).

The language background is one of the variables that moderate the relationship between reading comprehension and mathematics skills. Many studies reveal that mathematics achievement scores of first language learners are significantly higher than that of second-language learners (e.g., Martiniello, 2008; Goodrich & Namkung, 2019; Trakulphadetkrai et al., 2020). Second language learners' difficulties in reading comprehension cause them to lag behind their peers, especially in mathematics. Moreover, recent studies (Goodrich & Namkung, 2019; Trakulphadetkrai et al., 2020) reveal that there are differences in the relationship between mathematics skills and reading comprehension for first language learners and second-language learners. For example, Goodrich and Namkung (2019) and Trakulphadetkrai et al. (2020) find a strong relationship (r = .74) between problem-solving and reading comprehension for second language learners, whereas a weak or nonsignificant relationship (r = .49) between problem-solving and reading comprehension is obtained for first language learners. Although it can be argued that the relationship between reading comprehension and mathematics skills is stronger for second-language learners than for first-language learners, more extensive research is needed to confirm this claim.

Many studies have explored the relationship between mathematics skills and reading comprehension in both typical development students and students with learning disabilities (e.g., Alloway, 2007; Pimperton & Nation, 2010; Boonen et al., 2014; Fuchs et al., 2015; Bullen et al., 2020; Pongsakdi et al., 2020). Previous studies have shown that students with learning disabilities often struggle in both reading and mathematics (e.g., Lerkkanen et al., 2005; Bae et al., 2015; Salihu et al., 2018). Moreover, Lerkkanen et al. (2005) have argued that students with reading disabilities probably have difficulties in arithmetic skills and problem-solving. The presence of large comorbidity between dyslexia and dyscalculia prompted researchers to examine the association between reading comprehension and mathematics skills in students with learning disabilities (Ostad, 1998; Fuchs & Fuchs, 2002; Pimperton & Nation, 2010). Since students with learning disabilities, such as Autism Spectrum Disorder (ASD), specific language impairment (SLI), and attention-deficit/hyperactivity disorder (ADHD), are likely to have deficits in reading comprehension, their deficits in reading comprehension are likely to influence their mathematics skills (Whitby & Mancil, 2009; Bae et al., 2015; Bullen et al., 2020). For example, students with SLI have difficulty in mathematics and exhibit poor performance regarding arithmetic skills (Koponen et al., 2007). A recent article has revealed that a strong association (r = .58, r = .52) was obtained between reading comprehension and arithmetic skills or problem-solving in students with ADHD, a strong relationship (r = .51) was found between reading comprehension and problem-solving in students with ASD, and a non-significant relationship was obtained between reading comprehension and problem-solving or arithmetic skills in typical development students by Bullen et al. (2020). However, several studies (e.g., Bae et al., 2015; Salihu et al., 2018) show a greater relationship between reading comprehension and arithmetic skills or problem-solving in students with typical development than in students with learning disabilities. Given the effects of developmental issues on reading comprehension, more extensive studies comparing the relationships between reading comprehension and mathematics skills among developmental status groups (i.e., students with or without learning disabilities) may be crucial.

The Present Research

There is a growing need for meta-analytic research that provides a comprehensive and updated perspective on the association between mathematics skills and reading comprehension in the literature. Therefore, this research seeks to illuminate the nature of the association between reading comprehension and mathematics skills by incorporating potential moderators, namely components of mathematics skills, domains of content standards in mathematics, age, language status, and developmental issues (i.e., with or without learning disabilities). Thus, the research questions in this study are:

i) Is there a significantly positive association between reading comprehension and mathematics skills?

ii) Does the association between reading comprehension and mathematics skills vary according to potential moderators?

METHOD

Research Design

As this research illuminated the association between reading comprehension and mathematics skills, the meta-analysis design was used in the present research. Meta-analysis allows researchers to make statistically accurate estimates since it is an analysis of analyses (Shelby & Vaske, 2008; Güzeller & Çeliker, 2019). Based on meta-analysis research, the results of various independent research studies on a specific subject were systematically collected, then these findings were combined and synthesized, and finally, a statistical analysis of the combined results was performed (Shelby & Vaske, 2008; Borenstein et al., 2009; Güzeller & Çeliker, 2019).

Literature Search and Inclusion Criteria

A wide range of academic databases is available for screening scientific studies. In this study, the databases Web of Science, Scopus, Google Scholar, ERIC, EBSCOhost online, and ProQuest Dissertations & Theses were searched for research reports with the combinations of the keywords "reading comprehension," "passage comprehension," "text comprehension," "mathematics skills," "mathematical ability," "mathematics achievement," "mathematical performance," and "mathematics success" for the years between January 1990 and December 2020. Besides, the selection of reports was based on the PRISMA protocol for meta-analysis (Moher et al., 2009). A total of 274 reports, including research articles and dissertations, were selected from these academic databases after searching all research related to reading comprehension and mathematics skills. Then, the abstracts of these reports were reviewed using inclusion and exclusion criteria. Eighty-five reports were excluded at the abstract level since they were deemed inappropriate. The remaining 189 reports were analyzed in detail for their appropriateness against the inclusion criteria after reviewing the full text of the remaining reports. Duplicate reports were eliminated based on title and author information (n = 34). Nine reports were excluded because they reflected the literature review. Thirty-seven reports were eliminated since they were qualitative research. Twelve reports were excluded because they did not examine mathematics achievement tasks or reading comprehension. Forty-three reports were eliminated since they did not show a correlation between reading comprehension and mathematics skills. Five reports were removed because they were a pre-post-test design that did not reflect a correlational study. Thus, 140 reports were eliminated in this meta-analysis. In total, 49 reports met the inclusion criteria listed below (Figure 1):

- The research had to be published between 1990 and 2020.
- The research had to report the association between reading comprehension and mathematics skills.
- The research had to measure both reading comprehension and mathematics skills with any measure of task.
- The research had to include the statistical data necessary for this meta-analysis research (i.e., r, R^2, and N).
- Participants in the research had to be elementary, middle, or high school students.
- The research participants had to be either typical development students or students with learning disabilities.
- The research participants had to be either first language learners or second language learners.

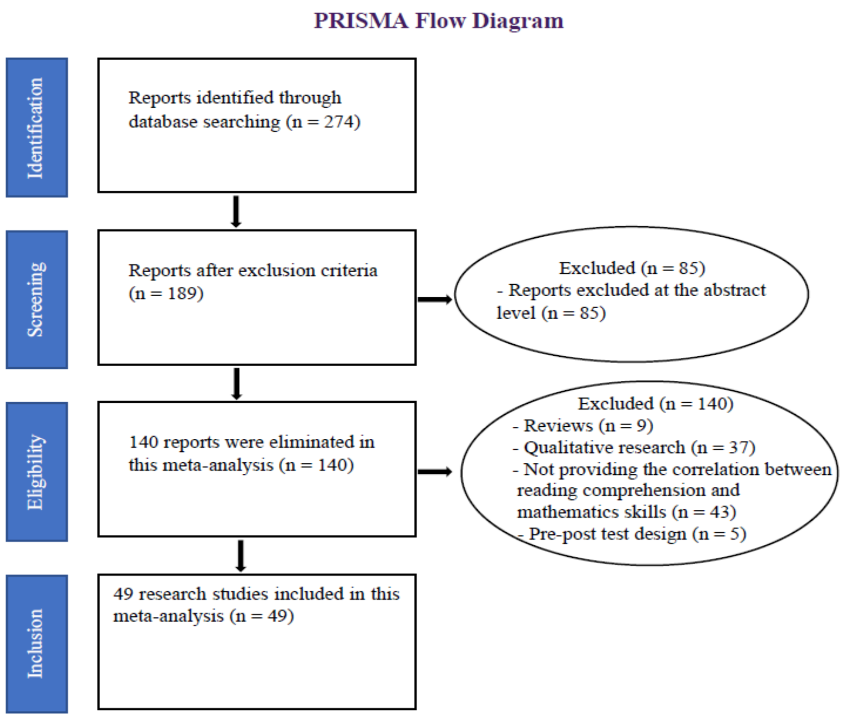

Figure 1. The PRISMA flow diagram associated with the present study

Coding Procedure

To reveal the association between reading comprehension and mathematics skills, components of mathematics skills, domains of content standards in mathematics were considered. Mathematics skills were coded as problem-solving, arithmetic skills, spatial skills, and logical reasoning. Content standards in mathematics were coded as numbers and operations, algebra, geometry, and mixed (i.e., including all domains of content standards) in the context of previous research on the association between mathematics skills and reading comprehension. To account for the effects of age on reading comprehension, the grade level of students was separated into three groups' namely elementary, middle, and high school in this study. To consider the effects of developmental issues on reading comprehension, developmental status was coded as typical development students and students with learning disabilities. Language status was also coded as first and second language learners. The coding form was composed of the categories of identification tag, the number of students, grade level of students, language status, developmental issues, mathematics skills, domains of content standards in mathematics, and correlation coefficients. The present research performed a meta-analysis of 49 research, with 91 effect sizes to investigate the correlation between reading comprehension and mathematics skills. The descriptive characteristics of these 49 studies with 91 effect sizes are provided in Table 1. Additionally, two researchers coded these individual studies separately and reached a nearly excellent agreement with Cohen's kappa coefficient of .92.

Table 1. Descriptive characteristics of the meta-analysis dataset

Variables	*f*	%
Components of mathematics skills		
Arithmetic skills	29	31.9
Spatial skills	10	11
Logical reasoning	8	8.8
Problem-solving	44	48.3
Domains of content standards in mathematics		
Numbers and operations	62	68.1
Algebra	2	2.2
Geometry	14	15.4
Mixed	13	14.3
Grade level of students		
Elementary	53	58.2
Middle	28	30.8
High	10	11
Developmental issues		
Typical development	76	83.5
Learning disabilities	15	16.5
Language status		
First language	85	93.4
Second language	6	6.6

Data Analysis

Correlation coefficients were seen as a measure of effect size to show the association between mathematics skills and reading comprehension. The effect size of each research was calculated independently since the unit of analysis was considered for each research in the meta-analysis (Kaya & Erdem, 2021). In this research, all analyses were conducted using the transformed Fisher's z values of all correlation coefficients and then all Fisher's z values were transformed back into correlation coefficients in an attempt to interpret easily (Güzeller & Çeliker, 2019; Xie et al., 2020). Also, it is assumed that each group is independent research when research contains multiple samples. Moreover, each component of mathematics skills is considered independent research when multiple mathematics skills are measured in research. Therefore, 49 studies with 91 effect sizes were included in this meta-analysis research. The range of values suggested by Cohen (2007) was utilized to evaluate the effect sizes. The test of homogeneity (Q statistic) and the test for heterogeneity (I^2) were conducted to assess whether a fixed or random-effects model fit the data set of this meta-analysis (Higgins et al., 2003; Güzeller & Çeliker, 2019). Funnel plot and Egger's regression were considered in this meta-analysis to investigate publication bias. Subgroup analysis was performed to investigate whether the association between reading comprehension and mathematics skills was moderated by components of mathematics skills, domains of content standards in mathematics, age, language status, and developmental issues. The *Q*-between-groups test was conducted to analyze whether or not the effect size distribution differed significantly by subgroups/moderators (Kaya & Erdem, 2021). Moreover, meta-regression was conducted to evaluate the effects of multiple covariates on mean effect size (Borenstein et al., 2014; Xie et al., 2020). The Comprehensive Meta-Analysis (CMA Ver. 2.0) program (Borenstein et al., 2014) and JASP (JASP Team, 2020) were used for analyses.

RESULTS

General Characteristics of Research Data

The dataset for this study included 49 studies with 91 correlation coefficients representing 37.654 participants. The number of participants varied between 39 and 5162. In Table 2, the I^2 value (I^2 = 91.73) showed that the effect size distribution was extremely heterogeneous according to the criteria of Higgins et al. (2003). The test of homogeneity revealed that the Q value (1088.03, p < .05) was significant in this study (Güzeller & Çeliker, 2019). Therefore, analyses in this study were estimated using a random-effect model. The mean effect size of reading comprehension on participants' mathematics skills was r = .50, with a 95 percent confidence interval varying between .47 and .52. This statistically significant value revealed that reading comprehension had a large effect size on mathematics skills of K-12 students based on Cohen's (2007) criteria (Oh-Young et al., 2018).

Table 2. General characteristics of research data

		95% CI					ToH		
Relationship	***k***	***n***	**ES**	**LL**	**UP**	***p***	***Q***	***p***	***I*²**
RC → MS	91	37,654	.50**	.47	.52	.00	1088.03**	.00	91.73

RC reading comprehension; MS mathematics skills; CI confidence interval; ToH test of homogeneity **p < .01

Moderator Analyses

The present potential moderators were identified in this study: components of mathematics skills, domains of content standards in mathematics, grade level of students, developmental issues, and language status. These potential moderators were performed in subgroup analyses to unpack whether the association between mathematics skills and reading comprehension differed, or not. The results of subgroup analyses indicated that the association between reading comprehension and mathematics skills differed significantly by components of mathematics skills ($Q_b(3)$ = 15.61, p < .01). The mean effect sizes between reading comprehension and arithmetic skills (r = .45, 95% CI [.41, .52], p < .01), spatial skills (r = .36, 95% CI [.26, .46], p < .01), logical reasoning (r = .46, 95% CI [.35, .55], p < .01), and problem solving (r = .55, 95% CI [.51, .58], p < .01) were significantly positive as shown in Table 3. Meta-regression analyses demonstrated that the mean effect size of problem solving was significantly greater than for arithmetic skills (β = −.08, z = −2.75, p < .01), spatial skills (β = −.18, z = − 4.24, p < .001), and logical reasoning (β = −.11, z = −2.27, p < .001). Moreover, the mean effect size of arithmetic skills was significantly greater than spatial skills (β = −.10, z = −2.14, p < .01). Likewise, the effect size of logical reasoning demonstrated significant difference between spatial skills (β = −.11, z = −2.26, p < .05), along with mean effect sizes of arithmetic skills and logical reasoning indicated relatively equivalent relations between reading comprehension and mathematics skills.

As shown in Table 3, the association between mathematics skills and reading comprehension differed significantly by domains of content standards in mathematics ($Q_b(3)$ = 14.67, p < .01). The mean effect sizes between reading comprehension and numbers and operations (r = .51, 95% CI [.48, .55], p < .01), algebra (r = .54, 95% CI [.34, .69], p < .01), geometry (r = .35, 95% CI [.27, 44], p < .01), and mixed (r = .52, 95% CI [.45, 59], p < .01) were significantly positive. Meta-regression analyses indicated that the mean effect size of geometry was significantly lower than for numbers and operations (β =.11, z = 2.93, p < .001), algebra (β = .18, z = 3.58, p < .001), and mixed (β = .15, z = 4.21, p < .01). Although algebra had the greatest effect size (r = .54), there were no significant differences in the mean effect size of algebra between numbers and operations ($\beta = -.01$, $z = -.08$, $p > .05$), and mixed ($\beta = -.002$, $z = -.03$, $p > .05$), individually.

There were significant differences between the effect sizes of studies constrained to age that involved elementary, middle, or high school students ($Q_b(2) = 9.99$, $p < 0.01$). The findings showed that the mean effect size between reading comprehension and mathematics skills was significantly positive for elementary ($r = .53$, 95% CI [.49, .57], $p < .01$), middle ($r = .46$, 95% CI [.41, .51], $p < .01$ and high school students ($r = .40$, 95% CI [.30, .49], $p < .01$). Based on the results of meta-regression, studies, including elementary students, demonstrated a significantly higher mean effect size than studies including middle school students ($\beta = -.10$, $z = -2.38$, $p < .05$) or high school students ($\beta = -.14$, $z = -2.28$, $p < .05$), while the association between mathematics skills and reading comprehension was not significantly higher for middle school students than for high school students ($\beta = -.04$, $z = -.61$, $p > .05$).

Based on developmental issues, the subgroup analysis indicated that the mean effect sizes for typical development students ($r = .48$, 95% CI [.45, .51], $p < .01$) versus students with learning disabilities ($r = .57$, 95% CI [.50, .64], $p < .01$) differed significantly ($Q_b(1) = 4.7$, $p < .05$). Additionally, the mean effect size of studies involving students with learning disabilities was significantly larger than studies involving typical development students ($\beta = -.09$, $z = -2.32$, $p < .05$). Similarly, given language status, the findings revealed that the mean effect sizes for first language learners ($r = .48$, 95% CI [.46, .51], $p < .01$) versus second language learners ($r = .65$, 95% CI [.57, .72], $p < .01$) differed significantly ($Q_b(1) = 12.83$, $p < .01$). Also, the mean effect size of studies involving second language learners was significantly greater than studies involving first language learners ($\beta = -.16$, $z = -3.02$, $p < .01$).

Table 3. Association between reading comprehension and mathematics skills based on moderator analyses

Variables	***k***	***n***	***r***	***r* (95% CI)**	**Q_b (df)**
Components of MS					$15.61^{**}(3)$
Arithmetic skills	29	10715	$.47^{**}$	[.41, .52]	
Spatial skills	10	6722	$.36^{**}$	[.26, .46]	
Logical reasoning	8	1985	$.46^{**}$	[.35, .55]	
Problem-solving	44	18232	$.55^{**}$	[.51, .58]	
Domains of CSM					$14.67^{**}(3)$
Numbers and operations	62	23340	$.51^{**}$	[.48, .55]	
Algebra	2	743	$.54^{**}$	[.34, .69]	
Geometry	14	7606	$.35^{**}$	[.27, 44]	
Mixed	13	5965	$.52^{**}$	[.45, 59]	
Grade level of students					$9.99^{**}(2)$
Elementary	53	12376	$.53^{**}$	[.49, .57]	
Middle	28	22057	$.46^{**}$	[.41, .51]	
High	10	3221	$.40^{**}$	[.30, .49]	
Developmental issues					4.70^{*} (1)
Typical development	76	35767	$.48^{**}$	[.45, .51]	
Learning disabilities	15	1887	$.57^{**}$	[.50, .64]	
Language status					$12.83^{**}(1)$
First language learners	85	33929	$.48^{**}$	[.46, .51]	
Second language learners	6	3725	$.65^{**}$	[.57, .72]	

MS mathematics skills; CSM content standards in mathematics; $^{*}p < .05$; $^{**}p < .01$

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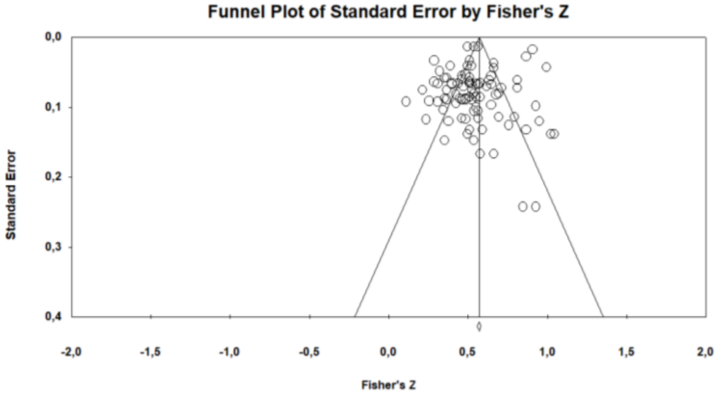

Figure 2. Visualization of effect sizes in the funnel plot

Publication bias analyses were conducted to investigate whether the dataset of this meta-analysis was influenced by publication bias. As presented in Figure 2, the funnel plot analysis revealed a reasonable symmetrical distribution. Based on Egger's test analysis (t = 1.23; p = .22), the mean effect size of the data set did not result in publication bias (Egger et al., 1997). In Table 4, the results of Duval and Tweedie's trim-and-fill test demonstrated that there was no difference between the observed values and the adjusted values. Therefore, no evidence of publication bias was obtained in this study.

Table 4. The findings of Duval and Tweedie's trim-and-fill test

	Studies trimmed	**ES**	**95% CI**		***Q***
			LL	UL	
Observed		.50	.47	.52	1088.03
Adjusted	0	.50	.47	.52	1088.03

DISCUSSION

The present research examined the nature of the association between reading comprehension and mathematics skills by incorporating potential moderators, namely components of mathematics skills, domains of content standards in mathematics, age, language status, and developmental issues. Based on Cohen's (2007) criteria (Oh-Young et al., 2018), the results demonstrated that there was a significantly strong and positive association between mathematics skills and reading comprehension (r = .50, 95% CI [.47, .52]). This finding is largely consistent with the results obtained from previous research that has revealed reading comprehension to be significantly, strongly, and positively associated with mathematics skills of K-12 students (e.g., Vilenius-Tuohimaa et al., 2008; Boonen et al. 2013; Schaffner & Schiefele, 2013; Bullen et al., 2020). Similar to the findings obtained in this study, a significantly strong and positive association was found between reading comprehension and mathematics skills in genetic research (Plomin & Kovas, 2005; Harlaar et al., 2012). In contrast, this result is inconsistent with only few studies, which indicated that the association between reading comprehension and mathematics skills is not statistically significant or weak (e.g., Imam et al., 2013; Bullen et al., 2020; Trakulphadetkrai et al., 2020). The significantly strong and positive association between reading comprehension and mathematics skills obtained in this meta-analysis research supports the literature and confirms the claim that reading comprehension is a strong predictor of mathematics skills (Mckee, 2012; García-Madruga et al., 2014). Moreover, the findings showed that the association between reading comprehension and mathematics skills was significantly moderated by components of mathematics skills, domains of content standards in mathematics, age, language status, and developmental issues.

To investigate the moderator effect in the context of the components of mathematics skills, the relationship between each component of mathematics skills was tested with reading comprehension. Results indicated that each component of mathematics skills was significantly associated with reading comprehension. Problem-solving (r = .55) had a significantly greater relationship with reading comprehension than arithmetic skills (r = .45), spatial skills (r = .36), and logical reasoning (r = .46). Likewise, both arithmetic skills and logical reasoning showed a significantly stronger relationship with reading comprehension compared to spatial skills. On the contrary, logical reasoning and arithmetic skills showed comparable relationships with reading comprehension.

Drawing on the findings reported above, it was revealed that problem-solving was influenced by reading comprehension more. These results are not surprising since one of the most important phases of problem-solving is understanding the problem (Lau, 2006). It is the most important action for students to attempt to comprehend the problem since it is unlikely that a problem can be solved without comprehending it (Ozturk et al., 2020). Previous research has also shown that even mathematically strong children have difficulty solving problems owing to an incorrect comprehending of the problem situation or limited reading comprehension skills (e.g., Bjork & Crane, 2013; Boonen et al., 2014; Özcan & Doğan, 2018; Can, 2020). Moreover, most previous studies indicate that reading comprehension has a stronger impact on problem-solving than arithmetic skills, logical reasoning, and spatial skills (e.g., Lee et al., 2004; Hart et al., 2010; Bjork & Crane, 2013; Harlaar et al., 2012; Fuchs et al., 2015; Murrihy et al., 2017; Pongsakdi et al., 2020). Therefore, this finding is consistent with the studies in the literature on reading comprehension and mathematics skills.

Problem-solving demonstrated the strongest relationship with reading comprehension, which was in line with the research hypothesis. This result can be explained by task complexity (Peng et al., 2019). Problem-solving skills are more complex than arithmetic skills since solving real-world problems requires reading comprehension skills and arithmetic skills (Bjork & Crane, 2013). Although logical reasoning and spatial skills require students to use more complex skills, such as comparison, generalization, induction, analysis, visualization, spatial memory, spatial orientation, and spatial perception, there is a unique association between problem-solving and reading comprehension since reading comprehension has a unique role in problem-solving process (Lin, 2011; Bjork & Crane, 2013).

Spatial skills showed a weaker relationship with reading comprehension than problem-solving, arithmetic skills, and logical reasoning. This result can be explained by the nature of spatial skills. In the literature, tests that measure spatial skills are generally composed of items containing spatial shapes or figures, and they are closely associated with mental rotation, spatial orientation, spatial memory, and visualization process (Xie et al., 2020). These test items are generally represented by spatial shapes or figures (Ünlü & Ertekin, 2017). To solve the tests of spatial skills, students, first of all, attempt to comprehend spatial shapes or figures rather than to comprehend the text. Therefore, it can be suggested that the visualization process or comprehending spatial figures replace reading comprehension when students use spatial skills.

The present research showed that the relationship between reading comprehension and mathematics skills differed significantly by domains of content standards in mathematics. Moreover, results revealed that each domain of content standards in mathematics was significantly related to reading comprehension. Geometry (r = .35) demonstrated a weaker relationship with reading comprehension than numbers and operations (r = .51), algebra (r = .54), and mixed (r = .52). On the contrary, numbers and operations, algebra, and mixed (i.e., including all domains of content standards) showed comparable relationships with reading comprehension. One possible explanation is related to the nature of geometry, which is an important part of mathematics, and it deals with geometric shapes, geometric objects, their positioning in the real world, and spatial relationships (Ünlü & Ertekin, 2017). Problems associated with geometry are generally presented with visual format rather than text format (Xie et al., 2020). When solving geometric problems, it is a priority to make sense of geometric figures or shapes in the problem rather than comprehend the text. Therefore, this result supports the research hypothesis. Although algebra had the greatest effect size, the mean effect size of algebra and reading comprehension was not significantly greater than numbers and operations or mixed. This result is not in conformity with the research hypothesis. To solve algebraic word problems, a student needs to convert words into the language of algebra and to switch between the language of algebra and text language appropriately (Özcan & Doğan, 2018). Cummins et al. (1988) have stated that students' performance in algebraic word problems depends on their mathematical knowledge and their reading comprehension skills. Moreover, they emphasize that errors related to algebraic word problems result from miscomprehending the problem. This finding can be explained by one possible explanation that only two studies associated with algebra in this meta-analysis lead to moderate heterogeneity (I^2 = 64.66) and make estimations about the relationship between algebra and reading comprehension less certain (Higgins et al., 2003). If the number of studies related to algebra is adequate regarding heterogeneity within the scope of reading comprehension, the number of effect sizes will increase in future meta-analysis studies. Therefore, an adequate number of effect sizes for algebra will make the association between reading comprehension and mathematics skills more certain.

Given the effects of age on reading comprehension, the moderator variable of the grade level of students is considered. This research revealed that reading comprehension had a significantly strong effect on students' mathematics skills at elementary school grades (r = .53), whereas reading comprehension had a significant medium effect on students' mathematics skills at middle (r = .46) and high school grades (r = .40). The results showed that the effects of reading comprehension on students' mathematics skills significantly differed in favor of younger students, which was in accordance with the research hypothesis. Previous research revealed that the association between mathematics skills and reading comprehension was significantly larger for elementary students than for middle and high school students (e.g., Björn et al., 2016; Salihu et al., 2018). This result can be explained by one possible explanation that younger students have less reading comprehension skills than middle and high school students, leading them to perform poorly when solving problems (e.g., Broek, 1997; Chae, 2004).

The present study demonstrated that the relationships between mathematics skills and reading comprehension were significantly positive for both typical development students (r = .48) and students with learning disabilities (r = .57). Moreover, the effects of reading comprehension on students' mathematics skills significantly differed in favor of students with learning disabilities, which was in line with the research hypothesis. One possible explanation is that since students with learning disabilities, such as ASD, SLI, and ADHD, are likely to have deficits in reading comprehension, their deficits in reading comprehension are likely to influence their mathematics skills (Whitby & Mancil, 2009; Bae et al., 2015; Bullen et al., 2020). The findings of a recent study have revealed that children who have mathematical disabilities are slightly more than twice as likely to have reading disabilities compared to typical development students (Joyner & Wagner, 2020). In consequence, it is an expected result that there is a significantly greater association between mathematics skills and reading comprehension in students with learning disabilities than in typical development students. Similarly, this study showed that the relationships between mathematics skills and reading comprehension were significantly positive for both first language (r = .48) and second language learners (r = .65). Moreover, the effects of reading comprehension on students' mathematics skills significantly differed in favor of second language learners, which was in line with the research hypothesis. Previous research indicated that second language learners' limited reading comprehension skills led them to be behind their peers, especially in STEM fields (e.g., Martiniello, 2008; Goodrich & Namkung, 2019; Trakulphadetkrai et al., 2020). Hence, we can argue that second language learners' mathematics skills can be influenced by reading comprehension more based on results.

Limitations

Several limitations were present in this meta-analysis. One of the limitations of this study was that the language of publications other than English was not considered in the present meta-analysis. Another limitation of the present study was related to the search strategy. In this study, generalized keywords, such as "reading comprehension," "passage comprehension," "text comprehension," "mathematics skills," "mathematical ability," "mathematics achievement," "mathematical performance," and "mathematics success" were considered. However, some publications may only engage in the specific components of arithmetic skills and spatial skills, such as "number sense," "number estimation," or "spatial orientation." Although it was intended to include all publications related to the research problem in this meta-analysis research, some eligible publications might have been overlooked on account of the search strategy. Moreover, an inadequate number of effect sizes for algebra made estimations about the moderator effect of algebra in the association between reading comprehension and mathematics skills less certain. Therefore, more effect sizes for algebra would be helpful to clarify this association in future meta-analyses. Additionally, gender could not be considered a potential moderator variable since many publications did not present the necessary data for this meta-analysis. Finally, several factors are related to mathematics skills, such as working memory, phonological processing, and general intelligence did not consider as a moderator between reading comprehension and mathematics skills. Therefore, further studies which include publications other than English and have sufficient data for potential moderators, such as genders, working memory, phonological processing, and general intelligence, are needed to illuminate the nature of the association between reading comprehension and mathematics skills by incorporating other potential moderators.

Conclusion and Implications

This study portrays the association between mathematics skills and reading comprehension using a meta-analysis. Drawing on findings obtained in this study, reading comprehension had a significantly strong effect on students' mathematics skills. This association was moderated by components of mathematics skills, domains of content standards in mathematics, age, language status, and developmental issues. Moderation analyses revealed that problem-solving was the strongest moderator of the association between reading comprehension and mathematics skills, whereas spatial skills were the weakest moderator of this relationship. Based on domains of content standards in mathematics, geometry was the weakest moderator of the association between reading comprehension and mathematics skills. Moreover, the effects of reading comprehension on students' mathematics skills significantly differed in favor of elementary students, students with learning disabilities, and second language learners. Therefore, this research can shed light on the literature by synthesizing the effects of reading comprehension on students' mathematics skills.

This study proved that mathematics skills and reading comprehension were causally interrelated. Thus, the findings obtained in this study provide some educational implications related to how to train reading comprehension skills to enhance students' mathematics skills. Language training should be integrated into mathematics learning and teaching to help students comprehend real-world problems (Bae et al., 2015) because it is crucial to concentrate on improving students' reading comprehension to assist them to steer the complex nature of reading texts and solving real-world problems in the context of mathematics (Bjork & Crane, 2013). To develop students' mathematics skills, mathematics teachers should provide students with opportunities to enhance reading comprehension skills, procedural and conceptual learning in mathematics, everyday vocabulary, and mathematics vocabulary in the learning environment (Bae et al., 2015). Meanwhile, continuous focus on improving students' reading comprehension is more likely to enhance their mathematics scores both in problem-solving and mathematics aptitude tests (Bjork & Crane, 2013). Mathematics teachers can incorporate reading comprehension skills into their mathematics teaching by asking children to read texts aloud, helping them interpret the problem situation based on the data and asking for what is desired in the problem, helping them use decoding skills, especially in complex problems, making them explore new words using every day and mathematics vocabulary (Carter & Dean, 2006). The present study showed that a considerable strong relation between reading comprehension and mathematics skills in elementary students, second language learners and students with learning disabilities. Hence, incorporating reading comprehension skills into mathematics instruction can benefit these three groups. Consequently, the findings suggest that mathematics instruction through reading comprehension skills, especially for elementary students, second language learners and students with learning disabilities should be enriched.

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