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Original Article

Investigation of Working Memory Performances of Children with Low Early Mathematics Achievement *

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Abstract

This study examined the working memory performance of children with low early mathematics achievement in comparison with their peers and analyzed the relationships between these skill areas. The distribution of children with low, average and high early mathematics achievement according to their working memory levels was also examined. The participants consisted of 100 kindergarten children with typical development and average and above-average intelligence. The Colored Progressive Matrices Test (CPM) was used to determine nonverbal intelligence levels, the Test of Early Mathematics Ability, Third Edition (TEMA-3) to evaluate early math skills and the Working Memory Scale (WMS) to determine working memory performances of the children. Children were divided into three groups of low, average and high achievement according to their early mathematics achievement assessed by the TEMA-3. It was found that the working memory performances of children with low, average and high achievement in early mathematics differed significantly. The working memory performance of children with low early mathematics achievement was significantly lower than their peers with average and high achievement. The results of the relationships between early math skills and working memory showed that early math skills and working memory components, except for visual short-term memory, were correlated to a small and medium degree. The distributions of working memory levels of the groups were examined and the results showed that children with low early mathematics achievement had low and average working memory performance, while children with high early mathematics achievement mostly had average and high working memory performance. However, none of the children with low early mathematics achievement showed high working memory performance. The results are discussed within the framework of the literature.

Keywords

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Introduction

Understanding mathematical concepts and performing mathematical operations are indispensable for human life in developed societies (Rourke & Conway, 1997). Mathematics is one of the most important skills for children to acquire academically and constitutes an important part of the curriculum, from preschool to the end of secondary education. Being able to perform mathematical operations is complex and requires many cognitive processes, such as attention, perception, memory and processing, to work together (Geary, 2011; Krajewski & Schneider, 2009; Passolunghi, Mammarella, & Altoe, 2008; Waltemire, 2018). If there is a problem in any of these processes, it is inevitable that children will fail to acquire mathematical skills. Mathematics is also a cumulatively progressive field in which basic mathematical knowledge and skills are prerequisites for advanced skills (Waltemire, 2018). For this reason, children who have problems in acquiring basic skills may also have problems in acquiring advanced skills (Jordan, Kaplan, Ramineni, & Locuniak, 2009; Mazzocco, 2007; National Mathematics Advisory Panel, 2008). Studies reveal that many children do not show success in mathematics appropriate for their grade level (Jordan et al., 2009). For instance, an Education Statistics Report published in 2019 stated that 20% of fourth-grade students and 30% of eighth-grade students do not even have a basic level of mathematics achievement (Snyder, de Brey, & Dillow, 2019). Some of these children have advanced difficulties and this may result in a diagnosis of mathematics disability. Approximately 5-10% of all school-age children are diagnosed with math disabilities (Barbaresi, Katusic, Colligan, Weaver, & Jacobsen, 2005; Shalev, 2007). Due to these high rates and the importance of mathematical skills both in academic life and in daily life, the factors affecting the development of these skills and underlying low mathematics achievement should be investigated (Duncan et al., 2007; Geary, 1994).

Although the teaching of mathematical skills begins in primary school, children begin to develop basic knowledge and skills in mathematics at an early age (Sarama & Clements, 2009). The knowledge and skills that children acquire in the early period are called early math skills. During this period, children can count numbers sequentially (Aunio & Niemivirta, 2010), understand the relationships between numbers and quantities (Dowker, 2008; Krajewski & Schneider, 2009), form patterns by looking at a simple model (Akman, 2019) and recognize basic geometric shapes (Clements & Sarama, 2000). They can also make measurements (Geist, 2009) using non-standard measurement units (step, span, etc.) and interpret the graphics created at a basic level (National Association for the Education of Young Children [NAEYC], 2008). These skills have formed the basis for success in mathematics in children's school life (Clements & Sarama, 2009; Duncan et al., 2007; Jordan, Glutting, & Ramineni, 2010; NAEYC, 2002). They also help children to understand mathematics more easily when they start primary school and are effective in achieving higher mathematics success (Duncan et al., 2007; Geary, Hoard, Nugent, & Bailey, 2013; Jordan, Kaplan, Locuniak, & Ramineni, 2007; Sarama & Clements, 2009). Children who show high performance in these skills generally have higher academic success (Duncan et al., 2007). Low performance may cause an increasing mathematical failure throughout the school period (Waltemire, 2018). Morgan, Farkas, and Wu (2009) found that the vast majority of children who underperformed in early math skills were similarly unsuccessful in math in the first, third and fifth grades.

Despite the importance of early math skills for later math achievement and general academic success, a significant proportion of children do not attain these skills to the level of their early childhood peers. Studies show that children's performance in early math skills is related to variables such as socioeconomic level, intelligence, number sense, language, working memory, processing speed and attention. Those who come from a low socioeconomic level and who are not given enough stimuli by their family (Arnold & Doctoroff, 2003; Cleveland, Jacobson, Lipinsky, & Rowe, 2000), who perform poorly in number sense (Griffin, Case, & Siegler, 1994), who experience language delays (Fuchs et al., 2005; Purpura, Hume, Sims, & Lonigan, 2011), who have a low intelligence level and poor performance in cognitive processes such as working memory, processing speed and attention (Espy et al., 2004) could not develop their early math skills to the desired level. Among these variables, the most emphasized variable is the limitations in working memory capacity (Bull & Scerif, 2001; Kroesbergen, Van Luit, & Naglieri, 2003; LeFevre, DeStefano, Coleman, & Shanahan, 2005; Raghubar, Barnes, & Hecht, 2010).

Working memory forms the basis of all learning experiences (Gathercole & Alloway, 2004) and enables incoming information to be combined with old information, associated and transformed into new information for learning to take place (Swanson & Beebe-Frankenberger, 2004; Swanson & Saez, 2003). It also controls attention and allows a person to ignore irrelevant information (Gathercole & Alloway, 2004). Working memory includes different components that interact and work in harmony with each other (Baddeley, 2000). Although different theoretical approaches are presented about the components of working memory, the most widely accepted is the multi-component model created by Baddeley and Hitch (1974). This model posits that working memory consists of three basic components: phonological loop, visuospatial sketchpad and central executive (Baddeley & Hitch, 1974). The phonological loop, also referred to as verbal short-term memory, stores verbal information for a short time. The visuospatial sketchpad, also called visual short-term memory, stores visual and spatial information for a short time (Gathercole & Alloway, 2008). These components do not perform any processing task (Baddeley, 2000); the control of both components and the processing of the stored information is provided by the central executive (Baddeley & Hitch, 1994; De Weerdt, Desoete, & Roeyers, 2013). Although the central executive is considered as a single component, the tasks of the central executive can be handled in two dimensions as verbal and visual working memory (Alloway, Gathercole, Kirkwood, & Elliott, 2008). Besides the task of processing verbal and visual information, the central executive manages attention, retrieval of information from long-term memory, selection of the appropriate strategy for processing information and integration of information obtained from different sources (Baddeley & Logie, 1999; Dehn, 2008). Working memory as a whole is seen as a highly effective structure for learning and is actively involved in all learning processes (Savage, Lavers, & Vanitha, 2007). Yet this structure, which is very effective in determining the learning, has a limited capacity and children can only hold and process a certain amount of information for a short time (Alloway, 2007).

There are significant differences in working memory capacity among children (Alloway & Gathercole, 2006). While some have a higher working memory capacity and can use the existing capacity more effectively, some may experience inadequacies in the capacity to store and process information and limitations in the effective use of the existing capacity, and thus fail in learning activities (Banich, 2009; Ropovik, 2014). Children with insufficient working memory capacity may encounter many problems, such as not being able to remember long instructions, make letter-sound correspondence and sound combinations while reading, or perform steps during a complex task, and may have difficulties in acquiring many academic skills (Alloway, 2008). Gathercole and Alloway (2008) stated that 80% of children with insufficient working memory capacity have difficulties in reading and math skills. For this reason, working memory is accepted as one of the main factors affecting learning level and academic achievement, and is frequently mentioned as an important factor explaining the performance differences seen in children concerning mathematical skills.

Many studies have shown that children who are unsuccessful in mathematics have poorer working memory performance than their peers (Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Passolunghi & Siegel, 2001, 2004; Swanson & Jerman, 2006). Passolunghi and Siegel (2001) found that fifth-grade students with math difficulties had lower verbal and visual working memory performances than their peers with average math achievement. In a similar study, children between the ages of seven and eight with low achievement in math showed poorer performance in the visuospatial sketchpad and central executive (Gathercole & Pickering, 2000). Gathercole et al. (2016) found that 52% of children aged six to seven years who showed low success in mathematics also had low working memory performance. In a study examining the relationships between mathematics achievement and working memory components, a moderately positive relationship was found between first-grade mathematics achievement and the visuospatial sketchpad and central executive, and between second-grade mathematics achievement and the phonological loop and central executive (De Smedt et al., 2009). There are also studies revealing that working memory components explain mathematics achievement to a large extent. While this rate is around 40% in some studies (Rasmussen & Bisanz, 2005), it increases up to 60% in other studies (LeBlanc & Weber-Russell, 1996). Working memory is therefore generally accepted as an important factor affecting performance differences in mathematics and this is supported by the findings of previous studies.

Working memory capacity is also an effective factor in the acquisition of early mathematics skills, which form the basis of children's mathematics success in school. Although studies explaining the relationships between early mathematics achievement and working memory are limited, they have shown that the relationships between these two variables are strong (Geary, 2010; Kroesbergen, Van de Rijt, & Van Luit, 2007; Locuniak & Jordan, 2008; Meyer, Salimpoor, Wu, Geary, & Menon, 2010). In one study, children aged four to seven years who were at risk for math difficulties performed quite poorly in terms of working memory components compared to their peers (Kyttälä, Aunio, & Hautamäki, 2010). Five-year-old kindergarten children with insufficient working memory capacity also had difficulties in early number skills and showed slower progress in the development of these skills (Toll & Van Luit, 2012). Simmons, Willis, and Adams (2012) found that the components of working memory explained 16% of the variance in number writing, 15% of the variance in number comparison and 19% of the variance in addition skills. There are also several studies showing strong relationships between early math skills and working memory performance of preschool children. For example, a study showed that there is a moderate relationship between kindergarten children's early number skills and their verbal and visual working memory performance, of .32 and .56, respectively (Kroesbergen et al., 2007). Simmons et al. (2012) examined the relationships between children's performance in early math skills such as number writing, magnitude judgment and single-digit arithmetic, and working memory components. They found a high level of relationship between central executive and addition, and a moderate relationship between working memory components and other early math skills. In our country, only one study has been conducted on the subject. This examined the relationships between children's working memory performance determined according to teachers' opinions and their success in mathematics such as ‘numbers’, ‘shapes’ and ‘dimensions/comparisons’ (Rezzagil, 2018). It found that working memory had a low relationship with mathematics achievement.

The present research is necessary for a number of reasons. First, the relationship between children's early math skills and working memory in our country may differ from the results of studies conducted in countries with different sociocultural structures, educational opportunities, quality and content of preschool education programs. For example, in the USA and many European countries, children start preschool education at the age of three and show a high rate of participation (95%) (Kazu & Yılmaz, 2018). There are content and process standards for early mathematics skills in preschool education programs (National Council of Teachers of Mathematics [NCTM], 2000). In Turkey, preschool education starts at a later age (five years old) and the participation rate (68%) is behind other countries (Ministry of National Education [MoNE], 2019). Unlike the programs in other countries, in the preschool education program in Turkey, mathematics is not considered as a separate discipline and the acquisition of early mathematics skills is included under the field of cognitive development (İncikabı & Tuna, 2012). Although the early mathematics skill areas in the content of the program overlap with the programs of other countries, the skills related to these areas are at a limited level (Pekince & Avcı, 2016). For example, in the USA the numbers skill area can be developed from rhythmic counting of one to 100, one-by-one and ten-by-ten, but in Turkey this is limited to rhythmic counting from one to 20, one-by-one (İncikabı & Tuna, 2012). Additionally, while the early mathematics skill areas of number sense and data analysis are included in the education programs of other countries, they are not in the preschool education curriculum in Turkey (Bozkurt, Şapul, & Dizman, 2020). Finally, children from low socioeconomic status receive less mathematical input in the family environment and have limited experience with these skills (Gürgah Oğul & Aktaş Arnas, 2020; Unutkan, 2007). Thus, we propose that the early math skills of preschool children in Turkey might be related to working memory and its components at different levels.

Second, there are several limitations to the current research. Only one study was conducted in Turkey examining children's early math skills and children's working memory performance was determined by teacher opinion (Rezzagil, 2018). There is a need for a more comprehensive evaluation of the working memory performance of children in Turkey and to examine the effect of working memory on performance differences in early math skills.

Third, children who have difficulties in early mathematics skills are more likely to have mathematics difficulties in the following years if they also perform insufficiently in working memory capacity. Children who perform poorly in both early math skills and working memory capacity are considered to be a risk group for math difficulties (Bull, Espy, & Wiebe, 2008). Tools for assessing working memory should be used in risk group screenings in the preschool period (Krajewski & Schneider, 2009; Kroesbergen et al., 2007). Therefore, investigating whether such a relationship exists in preschool children in Turkey is important in terms of identifying children at risk of mathematics difficulties in the early period.

This study was designed to respond to these needs. We aimed to examine the working memory performance of children attending kindergarten with low early mathematics achievement in comparison with their peers. We sought answers to the following questions:

1. When children with low early mathematics achievement are compared with their peers with medium and high early mathematics achievement,
   a. Is there a statistically significant difference in verbal short-term memory, verbal working memory, visual short-term memory, and visual working memory scores?
   b. Is there a statistically significant difference in working memory total scores?
2. What is the relationship between early math skills and working memory components?
3. What is the distribution of children with different levels of early math achievement in working memory performance levels?

Method

Model

We used correlational research, which is one of the basic research methods. A correlational study aims to determine the existence or degree of change between two or more variables (Karasar, 2014).

Study Group

Participants were selected by convenience sampling from children aged five to six years attending kindergartens in the Ankara province. In the 2018-2019 academic year, 15 schools in the three central districts of Ankara (Yenimahalle, Çankaya and Mamak) were approached and the study was carried out in a total of 10 schools, four from Yenimahalle, three from Çankaya and three from Mamak. The schools were randomly selected from those that were willing to take part.

Children who did not have any disability diagnosis and did not have any problems with attending school were identified. A consent document was sent to their families, which included detailed information about the study and notifying the children's consent to participate. Children of families who gave consent were also asked whether they wanted to participate in the study. The study included a total of 100 children, 10 from each school who were randomly selected from those who gave consent to participate. Around half (49) were girls and half (51) were boys. Their ages varied between 60 and 73 months, with an average age of 66 months. Children's non-verbal intelligence levels, determined by the CPM (Bildiren, Kargın, & Korkmaz, 2017), were average or above average.

The children were divided into groups according to their achievement levels in early mathematics skills (low, average and high), determined by the TEMA-3 (Erdoğan & Baran, 2006). This grouping was made according to the success level classification obtained by converting the raw scores obtained as a result of the TEMA-3 into mathematical ability scores (Baroody, Eiland, & Thompson, 2009). Accordingly, those scoring between 55 and 92 points (31 children) were included in the low achievement group, those between 93 and 107 points (45 children) were in the average achievement group and those between 108 and 130 points (24 children) were in the high achievement group. Table 1 shows the age, gender, status and duration of preschool education of the groups, and the age, education and employment status of the parents. As seen in Table 1, approximately a third of the children with normal development have low early mathematics achievement.

Table 1. The Distribution of the Groups Determined by Early Mathematics Achievement Levels by Age, Gender, Preschool Education Status and Duration, and Parent Age, Education and Employment Status

Group		**Low (*n* = 31)**	**Average (*n* = 45)**	**High (*n* = 24)**
Age (Month)	**M**	67.3	66.6	65.0
	SD	4	4	4
Gender	**G**	15	24	10
	B	16	21	14
Preschool Education Status	**Yes**	20 (%65)	31 (%69)	16 (%67)
	No	11 (%35)	14 (%31)	8 (%33)
Preschool Education Duration (Month)	**M**	12	13	12
	SD	12	11	11
Mother Age	**M**	35.3	35.2	33.9
	SD	6	5	3.4
Father Age	**M**	39.0	38.5	37.3
	SD	5	5	3
Mother Education Status	**PE**	2 (%6)	0 (%0)	2 (%8)
	SE	14 (%45)	15 (%33)	8 (%29)
	HE	15 (%48)	30 (%67)	15 (%63)
Father Education Status	**PE**	4 (%13)	4 (%9)	2 (%8)
	SE	12 (%39)	14 (%31)	5 (%21)
	HE	15 (%48)	27 (%60)	17 (%71)
Mother Employment Status	**Yes**	12 (%39)	25 (%56)	14 (%58)
	No	18 (%58)	20 (%44)	10 (%42)
Father Employment Status	**Yes**	30 (%97)	42 (%93)	24 (%100)
	No	0 (%0)	3 (%7)	0 (%0)

Note: M: Mean, SD: Standard Deviation, G: Girl, B: Boy, %: Percent, PE: Primary Education (Primary school, Middle school), SE: Secondary Education (High school), HE: High Education (Graduate, Postgraduate)

Data Collection Tools

Demographic Information Form

A demographics form was created to include questions about the child's information (date of birth, age, gender, preschool education status and duration) and the demographic characteristics of the parents (age, education and employment status).

Colored Progressive Matrices Test (CPM; Bildiren et al., 2017)

The CPM is used to evaluate the cognitive development of children between the ages of four and six. The first standardization study of this test was made by Raven in England in 1949. The test was adapted to Turkish by Bildiren et al. (2017) and a standardization study was carried out. The test consists of a total of 36 items split into three sets of 12, each containing forms A, AB and B. During practice, children are asked to indicate the missing piece of a pattern from among various options. The validity and reliability studies of the test were conducted with 640 children aged four to six years old. Within the scope of the validity studies, the criterion validity of the CPM was found to be .70 with the Bender Visual-Motor Gestalt Test, .63 with the Wechsler Intelligence Scale for Children (WISC-R) and .83 with the Test of Nonverbal Intelligence-3 (TONI-3). The item difficulty index of the CPM ranged between .06 and 1.00 in the A set, between .10 and .99 in the AB set and between .03 and 1.00 in the B set. The test-retest reliability coefficient was .55.

Test of Early Mathematics Ability (TEMA-3; Erdoğan & Baran, 2006)

The TEMA-3 is used to evaluate the mathematical skills of children between the ages of three and eight years 11 months. It consists of a total of 72 questions measuring informal mathematical fields such as more or less, counting and informal calculation, and formal mathematics such as numbers, relations between numbers, calculation and decimal concepts. There are two different forms of the test, A and B. The raw scores are converted into mathematics scores depending on the chronological age of the child. Classification is made for the level of mathematics achievement according to the mathematics score obtained (Baroody et al., 2009). Level equivalence and percentages for math ability scores are given in Table 2.

Table 2. Level Equivalence and Percentages According to Mathematics Ability Scores Obtained from TEMA-3

Mathematics Ability Scores	Level Equivalence	Percentages
55-69	Very Low	%0-%2
70-84	Low	%3-%16
85-92	Below Average	%17-%33
93-107	Average	%34-%67
108-115	Above Average	%68-%84
116-130	High	%85-%98

The validity and reliability study of the TEMA-3 in Turkey was conducted by Erdoğan and Baran (2006) for children in the 60-72-month group. For criterion validity, children with the best and the weakest level of mathematics achievement were determined according to the opinions of the teachers. The TEMA-3 Form A and Form B averages of the children at the best level ($\bar{X} = 23$) differed significantly from the Form A and Form B averages of the children at the weakest level ($\bar{X} = 8$). The test-retest reliability coefficients were between .88 and .90. The KR20 value for the internal consistency of the test was .92 for Form A and .93 for Form B. In this study, Form A was used to evaluate children's early math skills.

Working Memory Scale (WMS; Ergül, Özgür Yılmaz, & Demir, 2018)

The WMS is used to determine the working memory performance of children in the period from kindergarten to fourth grade (60-125 months). It consists of four sub-dimensions and nine sub-scales that evaluate verbal/visual short-term memory and verbal/visual working memory for verbal and visual memory. An increasing number of sequences is given for each sub-scale. Children are asked to repeat what is shown or said in tasks related to short-term memory and are given two-task operations that require simultaneous processing in tasks for working memory. By using the scores, standard scores, cut-off ranges and evaluation criteria (very low, low, average, high and very high) of performances according to age group can be determined. For validity studies, the goodness of fit statistics were calculated separately for all grade levels of the WMS. At the kindergarten level, these statistics were x^2=49.97 (N=860, df=25, p<.01), x^2/df=1.99, RMSEA=.08, RMR=.075, SRMR=.068, GFI=.93, AGFI=.88. For criterion validity, the correlations between the scores obtained from the Academic Achievement Scale at the kindergarten level and the total scores of the sub-scales of the WMS were examined and found to be ranged from .21 to .52. Trial total score correlations were calculated for the sub-scales for item discrimination of the WMS. These correlations ranged from .10 to .75 in the verbal sub-scales and between .11 and .72 in the visual sub-scales. The Cronbach's Alpha coefficient calculated for each sub-scale of the WMS ranged from .68 to .99. The test-retest reliability coefficients were between .41 and .83.

Data Collection

Permissions were obtained from the Ankara Directorate of National Education to carry out the study and from the Ethics Committee of Ankara University to determine the compliance of the study with ethical rules. Children were evaluated individually in a quiet room in their school. Evaluations were completed in two sessions. Each session lasted approximately 25-30 minutes. First, the CPM was given to 108 children to determine their non-verbal intelligence levels. According to the classifications obtained as a result of the test, eight children who were below average were excluded from the study, while 100 children who were average or above average were included in the study. Next, the TEMA-3 and WMS were applied within the scope of the research.

Data Analysis

In the process of analyzing the data, groups were first determined according to the mathematics ability score. The raw scores of the children obtained from the TEMA-3 A were converted into a Mathematics Ability Score (MAS) and grouping was made. However, we determined that the number of children in the 'very low' and 'high' level groups was very low. We therefore formed the 'low' group (55-92) by combining the very low, low and below-average groups, and the 'high' group (108-130) by combining the high and above-average groups. Accordingly, children were grouped into three levels of low, average and high.

All statistical analysis was performed using R Statistical Software. First, descriptive statistics on working memory and early math scores of the children were examined, outliers were identified and normality tests were conducted. According to the results of the normality test together with descriptive statistics including mean, mode, median and standard deviation values, the working memory total score, verbal working memory and verbal short-term memory scores of the children obtained from the WMS showed a normal distribution, but visual short-term memory and visual working memory scores did not. In addition, box plots showed no outliers. Accordingly, a one-way ANOVA was used for normally distributed data and the non-parametric Kruskal Wallis test was used for data that did not show a normal distribution. Differences between the groups were determined by the post hoc test for data showing a normal distribution and the Wilcoxon Rank Sum test for data not showing a normal distribution. Effect sizes were also calculated in all group comparisons. The relationships between early math skills and working memory scores were examined using Pearson's Product Moment Correlation Coefficient for normally distributed variables and Spearman's Rank Correlation Coefficient for non-normally distributed variables. A correlation coefficient between .70 and 1.00 was considered strong, between .70 and .30 as medium and between .30 and .00 as small (Büyüköztürk, 2010). Finally, a crosstab was used to determine the distribution of performance levels in working memory of children with different levels of early math achievement.

Results

First, group comparisons were made to determine whether there were significant differences in working memory components and general working memory of children with low early mathematics achievement compared to their peers with average and high early mathematics achievement. Second, the relationships between early mathematics achievement and working memory scores were examined. Finally, the distribution of children with low, average and high early mathematics achievement in different working memory performance levels was evaluated. The results of the analysis are presented below, respectively, depending on the research questions.

Verbal and Visual Short-Term Memory and Verbal and Visual Working Memory Scores

Verbal short-term memory scores of children with low, average and high early mathematics achievement were compared using the one-way ANOVA. Visual short-term memory and verbal/visual working memory scores were compared using the Kruskal Wallis test. The results are presented in Table 3.

Table 3. Groups' Verbal/Visual Short-Term Memory and Verbal/Visual Working Memory Scores

	Group	*n*	$\bar{X}$	*SD*	*F*	*p*	Sig. Difference	η^2
Verbal Short-Term Memory	Low	31	8.55	2.64	3.718	.03*	Low-Average Low-High	.07
	Average	45	10.18	3.12				
	High	24	10.63	3.56				
Verbal Working Memory	Low	31	1.06	1.26	10.524	.001***	Low-Average Average-High Low-High	.18
	Average	45	2.00	1.59				
	High	24	2.92	1.56				
	Group	***n***	$\bar{X}$	***SD***	x^2	***p***	**Sig. Difference**	***r***
Visual Short-Term Memory	Low	31	.84	1.00	1.80	.41	-	
	Average	45	1.20	1.20				
	High	24	1.25	1.39				
Visual Working Memory	Low	31	.58	.76	6.26	.04*	Low-High	.24
	Average	45	1.18	1.45				
	High	24	1.46	1.44				

*p<.05, ***p<.001

There are significant differences between groups in verbal short-term memory, verbal and visual working memory scores, but no significant differences between groups in visual short-term memory scores. There is a significant difference between all groups in verbal working memory scores, with a large effect size of .18. In verbal short-term memory, children with low early mathematics achievement differ significantly from children with average and high early mathematics achievement, with a medium effect size of .7. There is a significant difference between children with low early mathematics achievement and children with high early mathematics achievement in visual working memory scores, with a small effect size.

Working Memory Total Scores

The working memory total scores of children with low, average and high mathematics achievement were compared with the one-way ANOVA. The results are presented in Table 4.

Table 4. Groups' Total Working Memory Scores

Group	*n*	$\bar{X}$	*SD*	*F*	*p*	Sig. Difference	η^2
Low	31	457.35	47.96	12.694	.01**	Low-Average Average-High Low-High	.21
Average	45	506.80	71.77				
High	24	544.42	68.69				

**p<.01

There are significant differences between all groups in working memory total scores, with a large effect size of .21.

Relationship Between Early Mathematics Skills and Working Memory

The relationship between early math skills and working memory of the children was examined using Pearson's Product Moment Correlation Coefficient for verbal short-term memory, verbal working memory and working memory total score, and Spearman’s Rank Correlation Coefficient for visual short-term memory and visual working memory. The results are summarized in Table 5.

Table 5. Relationship between Early Mathematics and Working Memory

	Verbal Short-Term Memory	Verbal Working Memory	Visual Short-Term Memory	Visual Working Memory	General Working Memory
Early Mathematics	.33**	.42**	.14	.24*	.51**

*p<.05, **p<.001

Significant relationships range from .24 to .51. The strongest correlation is between early math achievement and working memory total score. While there is a moderately positive relationship between children's early mathematics achievement and verbal short-term memory, verbal working memory and general working memory performance, there is a low positive relationship with visual working memory performance. No significant correlation was found between early mathematics achievement and visual short-term memory.

Distribution of Working Memory Performance Levels of Children with Different Levels of Early Mathematics Achievement

The distributions of children with low, average and high early mathematics achievement in different working memory performance levels were examined by creating a crosstab. The results are presented in Table 6.

Table 6. Distribution of Children with Different Levels of Early Mathematics Achievement by Working Memory Performance Levels

Early Math Achievement Levels	**Working Memory Performance Levels**					
	Low		**Average**		**High**	
	n	**%**	***n***	**%**	***n***	**%**
Low (n = 31)	13	42	18	58	0	0
Average (n = 45)	12	27	21	46	12	27
High (n = 24)	4	17	9	37	11	46

Children with low early math achievement have substantially low (42%) and average (58%) working memory performance. Working memory levels of children with average early mathematics achievement showed a similar distribution in low and high working memory (27%) and accumulated in average working memory (46%). Children with high early math achievement mostly have average (37%) and high (46%) working memory performance. However, none of the children with low early math achievement showed high working memory performance.

Discussion and Conclusion

In this study, the working memory performance of children with low early mathematics achievement was compared with their peers and the relationships between early mathematics achievement and working memory were analyzed. The results revealed that children with low early math achievement generally outperform their peers with average and high achievement in all components of working memory. Early math skills were found to be associated with all other working memory variables except visual short-term memory. Additionally, a significant proportion of children with low early math achievement had low working memory. These findings are discussed in detail below according to the research questions.

In response to the first research question, children with low early mathematics achievement showed significantly lower performance in all working memory variables except visual short-term memory compared to their peers in other achievement groups. The effect sizes of the differences between the groups are moderate and strong in the variables of working memory other than visual working memory. These findings are consistent with the results of similar studies (Gathercole & Pickering, 2000; Geary & Hoard, 2001; Geary, Hoard, & Hamson, 1999; Gersten, Jordan, & Flojo, 2005; Hitch & McAuley, 1991; Passolunghi & Siegel, 2001; Swanson, 2006). Many studies have shown that working memory is effective in learning early number skills (Kroesbergen, Van Luit, Naglieri, Taddei, & Franchi, 2010; Kyttälä, Aunio, Lehto, Van Luit, & Hautamäki, 2003) and acquiring mathematical knowledge and skills (Bull & Scerif, 2001; Gathercole, Pickering, Knight, & Stegmann, 2004). Passolunghi and Siegel (2001) found that children with mathematical difficulties performed poorly in verbal working memory compared to their typically developing peers, while Siegel and Ryan (1989) reported that children with mathematics difficulties performed poorly in visual working memory. In addition, Swanson and Sachse-Lee (2001) revealed that the performance of children with low achievement in mathematics differed from their peers with high achievement in both general working memory and verbal working memory.

The findings of the present study suggest that two issues are important. First, if children with low early math achievement also have insufficient working memory capacity, the risk of experiencing math failures in the future increases. Even if children have difficulties only in early math skills, their difficulties may continue to increase in the following years. The difference in success between them and their peers may widen and they may not be able to acquire advanced skills. Many longitudinal studies have supported this picture. Morgan et al. (2009) followed children with math difficulties from kindergarten to fifth grade, finding that approximately 70% performed lower than their peers from kindergarten and that the gap between these children and their peers gradually widened in the following years. Children who have difficulties in basic math skills may also acquire advanced math skills late or not at all, since math skills are acquired cumulatively. The slow progress of these children in their math skills and the constant feeling of failure may cause them to develop negative attitudes towards mathematics and experience math anxiety. Early math anxiety, which occurs in the first years of school, can lead to an increase in math anxiety in the following years, resulting in dislike and avoidance of math (Wigfield & Meece, 1988). In addition to the fact that early failures in math skills are an important risk factor on their own, the limitations in working memory capacity increase the risk of mathematics difficulties and the level of possible failure. As emphasized in many studies, limitations in working memory capacity are accepted as a strong reason for failures in mathematics skills (Banich, 2009). Children with insufficient working memory capacity may have problems retrieving the information required for mathematical operations and may hold less information (Morgan et al., 2009). For example, they have difficulties in recognizing numbers and performing simple mathematical operations. These children cannot recognize numbers quickly and cannot automatically calculate simple mathematical operations such as 3+2=5 (Bull & Johnston, 1997). In addition, children with insufficient working memory capacity fail in skills such as mental arithmetic, calculation and problem-solving, as they lack ability at tasks such as holding the given information in mind for a sufficient time, or processing and retrieving the information or rules from memory (LeFevre, 1998; McCloskey & Macaruso, 1995; McCloskey, Caramazza, & Basili, 1985; Ropovik, 2014; Wilson & Swanson, 2001).

The second important issue is that the most effective working memory component in the early math skills evaluated in this study is verbal working memory. Children with low early mathematics achievement differed significantly from their peers in other components of working memory except for visual short-term memory, but the verbal working memory component strongly separated the groups. In addition, the variance explained by verbal working memory alone was 18%, while the variance explained by working memory performance was 21%. This result is quite remarkable and is largely consistent with the findings of other studies. Many studies indicate that children's mathematical success is explained by their performance in verbal working memory (Allen, Giofrè, Higgins, & Adams, 2020; Bayliss, Jarold, Gunn, & Baddeley, 2003; Friso-Van Den Bos, Van Der Ven, Kroesbergen, & Van Luit, 2013; Li & Geary, 2017; Wilson & Swanson, 2001). Wilson and Swanson (2001) stated that both visual working memory and verbal working memory predicted math performance, but verbal working memory explained 22% of the variance in math performance. Li and Geary (2017), in their study with seven-year-old children, found that verbal working memory predicted math skills more strongly. Bayliss et al. (2003) also stated that the performance in the working memory components of children aged seven to nine plays an important role in mathematics achievement, but verbal working memory is a more effective component. The fact that verbal working memory was found to be more effective on mathematics skills in these studies may be related to the fact that early mathematics skills include numbers and relationships between numbers. The use of verbal expressions of numbers (such as two, three) rather than symbolic representations of numbers (such as 2, 3) in preschool mathematics activities requires children to hold and process their mathematical knowledge in verbal memory. Therefore, children's verbal working memory capacity more strongly explains early math performance (Cragg, Keeble, Richardson, Roome, & Gilmore, 2017; Gersten et al., 2005). On the other hand, some studies show that visual working memory is more effective than verbal working memory (McLean & Hitch, 1999; Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2013). However, these studies were conducted with older age groups, in which mathematical skills with more visual elements generally increase. The findings of our study support the findings of previous studies and show that verbal working memory is an important component with a high impact on early math skills compared to the low impact of visual working memory.

In response to the second research question, the relationships between children's early math achievement and the sub-components of working memory were examined. The findings are similar to the findings for the first research question. The correlation between verbal working memory, where the difference between groups is more pronounced and early mathematics is stronger than other working memory components. There is a moderate correlation ($r=.33$ and $r=.42$, respectively) between verbal short-term memory and verbal working memory with early mathematics achievement and a weak correlation ($r=.24$) between visual working memory. The correlation between working memory total score and early mathematics achievement is moderate, at .51. Findings regarding both working memory components and working memory general performance are similar to the results of previous studies (Allen et al., 2020; Bull et al., 2008; Friso-Van Den Bos et al., 2013; Kroesbergen et al., 2007). Results from a meta-analysis showed that the strongest correlation was between verbal working memory and early mathematics, followed by visual working memory, visual short-term memory and verbal short-term memory (Friso-Van Den Bos et al., 2013). Pennington and Willis (2004) found a moderate correlation between five-year-old children's early math achievement and visual short-term memory and working memory performance. In another study, the results of the assessment of the mathematical success of children attending the first grade and the components of working memory showed that mathematics achievement was moderately correlated to each of the components of working memory (Bull et al., 2008).

In response to the last research question, the distribution of working memory levels of children in early mathematics achievement groups was examined. The results showed that none of the children with low early math achievement were at high working memory. Some 42% of these children have poor working memory performance. These findings are consistent with the results of previous studies. Gathercole et al. (2016) found that 52% of six- to seven-year-old children who performed poorly in mathematics also underperformed in working memory. These children have a very high risk of future mathematics failure. On the other hand, some children have low early math achievement despite having moderate working memory performance. Accordingly, although it is clear that working memory is an important factor affecting early mathematics achievement, it is not the only one. Many factors such as non-verbal intelligence, language, rapid naming, processing speed, socioeconomic level, math-specific input from parents, or the expectations of parents are frequently emphasized in the literature as variables that increase or decrease the risk of mathematical difficulties in children (Arnold & Doctoroff, 2003; Chard et al., 2005; Espy et al., 2004; Fuchs et al., 2005; Kleemans, Peeters, Segers, & Verhoeven, 2012; LeFevre, Polyzoi, Skwarchuk, Fast, & Sowinski, 2010). However, the relationship between working memory and early mathematics achievement, the rate of variance it explains and its power of influence show that it is a key factor affecting mathematics achievement.

Another remarkable aspect of the findings obtained in the study is the relationship with preschool education in Turkey. Although many studies have reported that the content of the preschool education program in Turkey regarding early mathematics skills is more limited compared to developed countries (e.g. İncikabı & Tuna, 2012; Pekince & Avcı, 2016), the number of children with low early mathematics achievement was limited in this study. According to the TEMA test scores, 100 children showed an approximately normal distribution, with 31 in the low, 45 in the average and 24 in the high group. We evaluated this situation as meaning that the limitations of early math skills in the preschool education program do not have a strong effect on children's early mathematics achievement. However, the effect of the preschool education program on early mathematics skills needs to be examined in more detail.

In summary, the most important finding of this study is that children with low early mathematics achievement performed poorly in working memory, especially in verbal working memory. It is clear that this situation will increase the probability of children having mathematical difficulties in the following years.

Limitations and Suggestions

Two important limitations should be considered. First, the generalizability of the results is limited, since this study was conducted with a sample of 100 children. Therefore, the study may need to be repeated with larger groups. Second, although the test used to evaluate children's early mathematics skills was adapted into Turkish, it does not have norms for Turkish children. Although mathematics skills are relatively less affected by language and culture, the development of an effective, reliable and Turkish-normed mathematics test that is suitable for Turkish children and measures early mathematics skills will make significant contributions to both research and practice.

We also have suggestions for future research. Researchers report that children with low early mathematics achievement will continue to have difficulties in the future. Longitudinal studies may be needed to see whether children's early mathematics difficulties continue in the following years and, if so, in which mathematics skills. Second, since different variables other than working memory, such as non-verbal intelligence, language, rapid naming and processing speed, affect performance differences in early math skills, longitudinal studies could investigate the contributions of each of these variables. Third, to better understand the relationships between working memory and early math skills, the contribution of each of the working memory components to each of the early math skills could be investigated separately.

We also have suggestions for practice. First, due to the high number of children with low early mathematics achievement, early intervention programs to address the difficulties these children experience could be developed and evaluated. Interactive and game-based programs can be developed based on the developmental characteristics of children. During the implementation of these programs, strategies to support working memory performance, such as using reminders, repetition and giving written or visual instructions, could be used (Kroesbergen, Van't Noordende, & Kolkman, 2012). Second, in addition to tools that assess early math skills, tools that assess working memory performance can be used in screening to identify children at risk for math difficulties. As verbal working memory more strongly explained the variance in early mathematics achievement, using only verbal working memory sub-scales to reduce the evaluation time may increase the effectiveness of the early diagnosis and intervention process.

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