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Effectiveness of Early Intervention Programs in Developing Early Mathematical Skills: A Meta-Analysis

Erken Matematik Becerilerinin Geliştirilmesinde Erken Müdahale Programlarının Etkililiği: Bir Meta-analiz Çalışması

Ensar YILDIZ* Özge KOCA** Şenel ELALDI***

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ABSTRACT: Early intervention includes approaches to responding to young children may profit from targeted services. This study aims to synthesize recent evaluations of intervention programs of Big Math for Little Kids, Building Blocks, and Prekindergarten Mathematics Intervention Program in preschool and kindergarten children to determine the effectiveness of early intervention programs including experimental studies in last 15 years in developing early mathematical skills. Among 146 studies, 10 studies that met the inclusion criteria, which included experimental studies, publication bias, effect size, heterogeneity, moderator type of intervention program, the duration of the intervention, and the participants' age. The results indicated a large effect size (Hedges'*g*=1.217) for the effectiveness of intervention programs according to random effects model and Cohen's classification. While the results of moderator analyses highlighted a statistically meaningful difference in implementation periods, no significant differences were observed in terms of type of intervention program and age variables. Although meta-analyses regarding the effects of math interventions on school age students are available, there are hardly any meta-analyses addressing early intervention programs for enhancing preschool and kindergarten children's math skills. The outcomes of the current study provided an evidence of the effectiveness of early intervention programs on math skills.

Keywords: Early intervention, mathematical skills, meta-analysis.

ÖZ: Erken müdahale, planlanan hizmetlerden fayda sağlayabilecek küçük çocukları desteklemeye yönelik yaklaşımları içerir. Bu çalışma, okul öncesi ve anaokulu çocuklarına yönelik Big Math for Little Kids, Building Blocks ve Prekindergarten Mathematics Müdahale programlarını sentezleyerek son 15 yılda deneysel çalışmaları içeren erken müdahale programlarının erken matematik becerilerini geliştirmedeki etkililiğini belirlemeyi amaçlamaktadır. 146 çalışma arasından deneysel çalışma, yayın yanlılığı, etki büyüklüğü, heterojenlik, müdahale programının aracı değişkeni, müdahale süresi ve katılımcı yaşları gibi dâhil edilme kriterlerini karşılayan 10 çalışma değerlendirilmiştir. Sonuç olarak, rastgele etkiler modeline göre ve Cohen'in sınıflandırmasına dayalı olarak müdahale programlarının etkililiğine ilişkin büyük bir etki büyüklüğü (Hedges'*g*=1.217) bulunmuştur. Moderatör analizleri sonuçları uygulama süreleri arasında istatistiksel olarak anlamlı bir farklılık ortaya koyarken, müdahale programı türü ve yaş değişkenleri açısından anlamlı bir farklılık gözlenmemiştir. Matematik becerilerine yönelik müdahalelerin ilkokul öğrencileri üzerindeki etkilerine ilişkin meta-analizler mevcut olmasına rağmen, okul öncesi ve anaokulu çocuklarının matematik becerilerini geliştirmeye yönelik erken müdahale programlarını ele alan meta-analizler neredeyse yoktur. Bu çalışmanın sonuçları, erken müdahale programlarının matematik becerileri üzerindeki etkililiğine dair bir kanıt sağlamıştır.

Anahtar kelimeler: Erken müdahale, matematik becerileri, meta-analiz.

* Asst. Prof. Dr., Sivas Cumhuriyet University, Sivas, Turkey, ensaryildiz@cumhuriyet.edu.tr, https://orcid.org/0000-0003-3741-1121
** *Corresponding Author:* PhD Student, Hacettepe University, Ankara, Turkey, ozge.koca@hacettepe.edu.tr, https://orcid.org/0000-0001-6040-7273
*** Prof. Dr., Sivas Cumhuriyet University, Sivas, Turkey, snlelaldi@gmail.com, https://orcid.org/0000-0003-0780-4207

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Mathematics is a powerful tool for understanding and exploring the world. The knowledge, skills and behaviors that children gain in the early childhood period form the basis of their future lives. Children need math skills in order to use analytical thinking and reasoning skills in the early childhood period. Analytical thinking refers to the ability to analyze cause-effect relationships in our environment and to think critically about the world (Brown et al., 2014). This skill has an important place in children's daily lives. Many skills in life, such as washing hands after the toilet and brushing their teeth before sleeping, require analytical thinking skills. In addition, mathematical concept development includes many cognitive processes involving early math skills such as perceiving similarities and differences, finding these similarities and differences, arranging, classifying, generalizing, counting and measuring skills (Kandir & Orcan, 2011). In fact, mathematics is not limited to numbers and figures. Mathematical words (such as hot, cold) are so common that they are often not even considered to belong to mathematics. Concepts such as "before", "soon", "later", "little", "in" and many more that are used dozens of times every day include math skills (National Council of Teachers of Mathematics [NCTM], 2010). Although mathematical development in the early childhood period shows individual differences, this development takes place in predictable stages. These stages include the skills of matching, classification, seriation, sorting and patterning. On the other hand, the concept of number appears as a prerequisite skill for many other math skills. It is necessary for children to have a good understanding of numbers in the early years so that they can learn mathematics in later years (Young & Loveridge, 2004). Therefore, it is clear that mathematics help preschoolers develop an understanding of spatial concepts, numbers and the ability to classify, sort and solve problems (NCTM, 2010). Moreover, there is a direct relationship between children's early math skills and their future academic success., higher grades, higher employment, and professional success (Harris & Petersen, 2019). Thus, gaining cognitive-based early math skills to young children is a strong predictive of later math achievement (Duncan et al., 2007). As in math success, some factors that influence math failure can begin to operate from an early age (Morgan et al., 2011). Therefore, early childhood math education is expected to meet the individual needs of students at different readiness stages, taking into account the effects of cultural backgrounds, previous experiences, learning styles, and cognitive abilities. Accordingly, it requires learning environments to be organized and orchestrated by teachers and other professionals (Björklund et al., 2020). As many children enter compulsory education with the need for early intervention, the importance of early intervention programs, supports and services for young children and their families is increasingly emphasized in early childhood (VanDerHeyden & Snyder, 2006). Quality interventions increase the chances of changing young children's developmental trajectories.

Early intervention is a term used to specify approaches to defining and responding to young children and their families who may profit from targeted services or supports to accelerate learning and growth (IDEA, 2004; as cited in VanDerHeyden & Snyder, 2006). Early intervention includes prevention rather than remediation, improving math learning for all young children, addressing the inequalities children face, and identifying young children who may need special help in participating meaningfully in early learning experiences (Clements & Sarama, 2009; VanDerHeyden

& Snyder, 2006). As the intervention programs, Big Math for Little Kids (BMLK), Building Blocks (BB) and Pre-K are included in this study as the programs that focus on math skills and are used in preschool and kindergarten children. BMLK is an intervention program developed by Ginsburg et al. (2003) to support the mathematical development of preschool children aged 61-72 months. It is a research oriented, well planned, comprehensive as well as entertaining math program. The program is to exploit the connections between young children's existing knowledge, experiences and skills, and their mathematical thinking involved in their daily experiences and other activities (Ginsburg et al., 2003). It ensures supporting opportunities for children to make mathematical explorations in an environment supported by rich as well as various stimuli. It purposes to help children reason and discuss their own explorations (Ginsburg et al., 2003). In the development of BMLK, the following principles of math curriculum were taken into account: (a) structuring children on their knowledge and interests; (b) integration with daily routine activities; (c) teaching and diversifying in a planned way; (d) supporting the development of complex mathematical ideas; (e) allowing them to use the language of mathematics; (f) supporting children to think like a mathematician; (g) allowing repetition (Greenes et al., 2004). The content of the BMLK curriculum consists of activities planned in six areas: numbers, shapes, measurement, patterns and reasoning, operations with numbers, position and direction relations (Morgenlander & Manlapig, 2006). Storybooks have been developed for each of these activities. The stories are designed to help children understand the deeper and bigger ideas associated with mathematical language. Children are given the opportunity to tell stories to each other, to complete the missing parts in the pictures, and to take the book home and read it with their families (Greenes et al., 2004). In line with the importance of early intervention in mathematics, there has been an increase in experimental studies on BMLK supporting math education in recent years (i.e., Altındag Kumas, 2020; Altındag Kumas & Ergul, 2021; Celik & Kandir, 2013; Kandir et al., 2017; Khomais, 2014; Kilickaya & Avci, 2021).

Developed by Sarama and Clements (2002) for young children aged 4-8, BB is a program designed by considering the mathematics standards developed by the National Council of Mathematics Teachers (NCTM, 2000). In the process of designing the program and materials, a research-based model was used. This model bases the instructional program and computer software program on a certain theoretical and empirical basis (Sarama & Clements, 2004). Considering this aspect, testing the effectiveness of the developed curriculum with experimental studies can be considered as another determinant of "research-based" status. In addition, the basic approach of BB is to reveal and develop mathematics from children's interests and experiences (Clements & Sarama, 2007). According to Sarama and Clements (2004), BB intervention program should: (a)be built on children's mathematical experiences; (b) provide a solid foundation for further mathematical studies; (c)deal with evaluation as an integral dimension of the learning process; (d) develop a strong conceptual framework that enables skill acquisition; (e) adopt the fact that children are doing math; (f) allow the development of children's reasoning abilities and mathematical thinking; (g) have an extensive content and; (h) be available for use of appropriate and continuous technology including computers and calculators. Some experimental studies evaluating the effectiveness of BB (i.e., Arteaga et al., 2019; Bojorquea et al., 2018; Clements &

Sarama, 2007, 2008; Sarama & Clements, 2002) have revealed positive effects on developing math skills in young children.

Pre-K was developed by Klein et al. (2002) in accordance with NCTM's standards. Pre-K is a support program arranged to improve the informal math knowledge and skills of preschool children (O'Dell, 2005). The primary goal of the program is to close the gap in mathematics achievement between children from low-income families and those from middle-class families (Klein et al., 2002). Pre-K was designed on a research basis and on the axis of sequence. Being research-based and sequence defines both the elimination of conceptual deficiencies in mathematics in children of low-income families and being associated with the development of mathematical concepts that they will need in formal mathematics education in primary school (Starkey et al., 2004). Pre-K program consists of activities organized in seven units related to mathematics. These are numbers and counting, understanding arithmetic operations, spatial perception and geometry, patterns, understanding arithmetic operations (higher level), measurement-data collection and reasoning (Klein et al., 2002). Based on these seven units, 32 small group activities and 21 home activities were designed. The activities have been prepared on the basis of children's interests and experiences and in a way that supports the development of mathematical thinking. The education program continues with both classroom activities involving manipulatives and painting completion activities at home. Home activities can be held in English or Spanish. Math concepts and skills presented in classrooms continue throughout the year as small group activities under teacher guidance. Children are presented with a new math activity twice a week as small group activities, and these presentations involve about 20 minutes of work with groups of 4 to 6 children. There are experimental studies showing that this program is especially effective on the math skills of economically disadvantaged children. In this regard, Nicoll (2007) stated that mathematical achievement levels of children from low-income families, where the Pre-K Program was applied for one year, reached almost the same level as the mathematics achievement level of middle-class family children who did not apply the program. Some experimental studies (i.e., Karakus, 2020; Kermani & Aldemir, 2015; Klein et al., 2011; Starkey et al., 2004) also revealed the effectiveness of the program.

Longitudinal studies of early math skills have indicated that they are definitive predictors of later math achievement (Braak et al., 2022; Navarro Soria et al., 2021, Ozcan & Dogan, 2018). Similarly, a meta-analytic study carried out Duncan et al. (2007) to reveal the strongest predictors of later achievement of preschoolers showed that early math skills came first as having the most considerable predictive power, followed by reading skills and then attention. On the other hand, a number of meta-analysis studies have focused on the effects of mathematics interventions on the mathematics achievement of school age students with diagnosed learning disabilities (i.e, Gersten et al., 2009; Kroesbergen & Van Luit, 2003; Methe et al., 2012; Swanson et al., 1999; Xin & Jitendra, 1999) or students at risk of math difficulties (Baker et al., 2002; Kunsch et al., 2007; Mononen et al., 2014). The literature review has clearly demonstrated that only two of these meta-analysis studies included preschool and kindergarten children's math skills (Malofeeva, 2005; Mononen et al., 2014). While the former meta-analysis study belonging to Malofeeva (2005) dealt with preschool and kindergarten children's mathematics learning, the latter belonging to Mononen et al.

(2014) included a meta-analysis of early numeracy interventions for preschool age children at risk for mathematics difficulties. However, a meta-analysis study to reveal the effect of intervention programs on early math skills of normally achieving preschoolers or kindergarteners has not conducted so far. Therefore, the aim of this study is to fill the research gap by synthesizing the studies using intervention programs within the context of the study designed to improve the early mathematics skills of normally achieving young children through meta-analysis.

Moderators a forehand in the current study include type of intervention program, duration of the intervention, frequency of application and participant's age. Early mathematics intervention programs exist to promote the development of basic math skills among young children in early childhood (Sarama & Clements, 2009). Thus, type of intervention program was defined as a program engaging young children in mathematical experiences. BMLK, BB and Pre-K intervention programs were considered as early intervention programs used to develop math skills. Duration of the intervention was based upon the time of intervention that each individual study reported. Durations were categorized as 6 weeks, 11 weeks, one semester and one school year. Frequency of application were categorized as 2 or 3 days in a week and every day in a week. Participant's age was defined as the age of the participant, as reported in the studies included. Age range was considered as 36-72 months, 48-72 months and 60-72 months for the study. These moderators are vital importance on effectives of intervention programs. This study will show us which type of intervention, duration, frequency and age are the most effective for children. Thus this study guides for policy makers, educators, teachers as soon.

The primary aim of this synthesis was to procure a systematic, extensive review of the present findings concerning the efficiency of early intervention programs (BMLK, BB and Pre-K) in developing early math skills. A secondary aim was to determine moderators of early intervention programs by investigating such possible moderators as type of intervention program, duration of the intervention, and participant's age. In this context, the following questions were included in the study:

1. What is the average/overall effect size level of the studies conducted between 2006 and 2021?
2. What effect does a type of intervention program have on early mathematical skills?
3. What effect does the duration of the intervention have on early mathematical skills?
4. What effect does age have on early mathematical skills?

Method

Meta-analysis provides a summary of data from a variety of quantitative studies by applying a structured and systematic process to provide more profound information than conventional qualitative descriptions (Lipsey & Wilson, 2001). In this regard, meta-analysis is a method of combining results of independent primary quantitative studies that share a similar subject area and performing a statistical analysis of the research findings obtained (Borenstein et al., 2009).

Data Collection

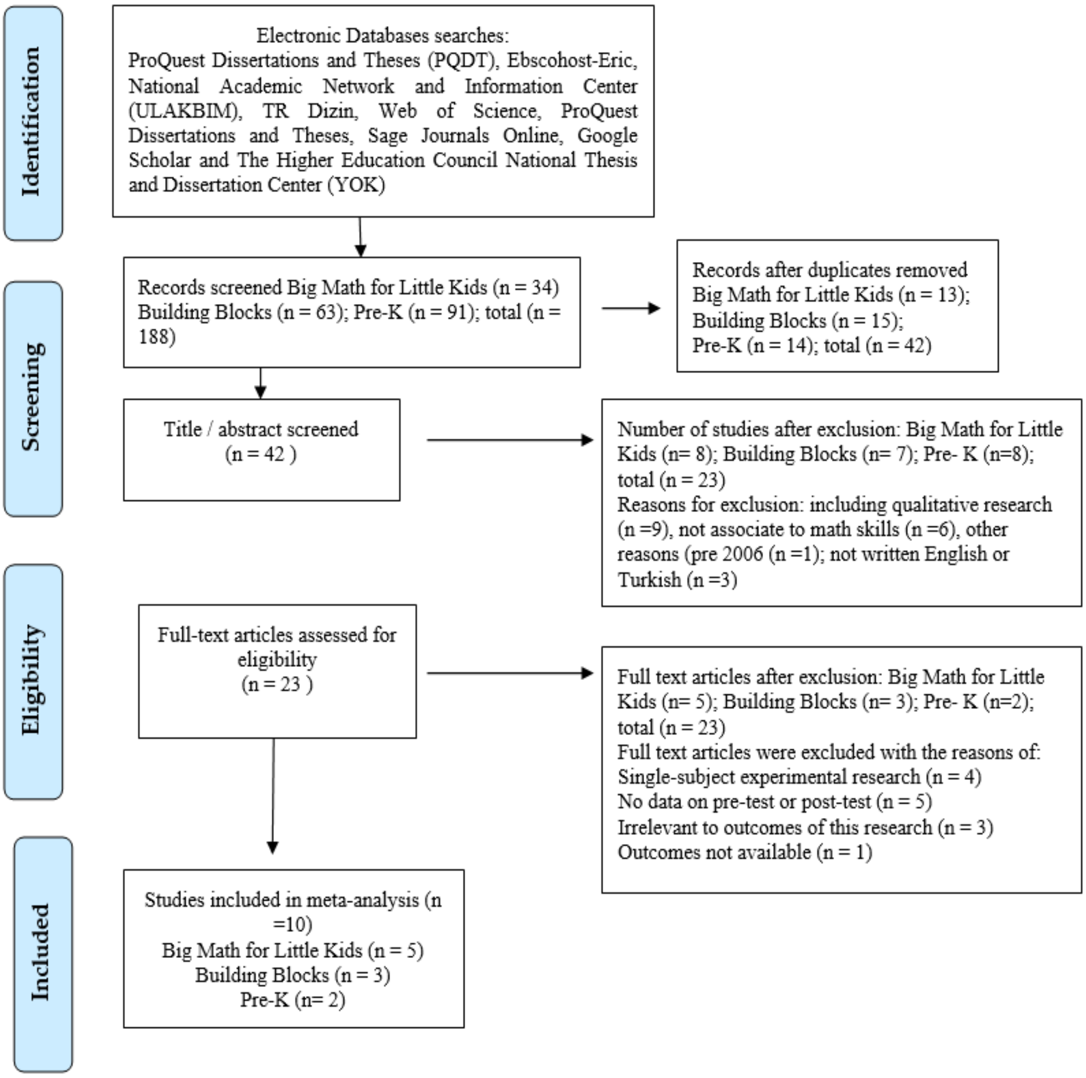
The studies on early intervention programs were detected in the databases of the Ebscohost-Eric, National Academic Network and Information Center (ULAKBIM), TR Dizin, Web of Science, ProQuest Dissertations and Theses, Sage Journals Online, Google Scholar and The Higher Education Council National Thesis and Dissertation Center (YOK) in January 2021. To obtain the relevant studies, the concepts of "early intervention programs" "use of early intervention programs", "intervention programs and preschoolers," "intervention programs and kindergartners", "intervention programs and effectiveness", and "intervention programs and early mathematical skills" were searched in the abstracts, index, and title search parts of the databases. As a result of the scanning, it was revealed that the studies gained intensity in three programs (The Big Math for Little Kids, the Building Blocks and The Pre-K). Therefore, electronic scanning was continued by including keywords "The Big Math for Little Kids and early mathematical skills", "The Building Blocks and early mathematical skills" and "The Pre-K and early mathematical skills". Then, all studies were sought out for inclusion of additional studies.

Inclusion and Exclusion Criteria

A set of inclusion criteria included: (1) The intervention programs of BMLK, BB and Pre-K used to develop preschoolers' or kindergartners' math skills. (2) Studies in which the recipients of the intervention were identified as normally achieving students. (3) Studies published in international peer-reviewed journals in English and non-English (Turkish) and unpublished theses and dissertations conducted in the last fifteen years (2006-2021). (4) Experimental studies that include sample sizes, and standard deviations, means or t-test values of both experimental and control groups belonging to pretest- posttest measurements. On the other hand, studies involving intervention programs other than these three programs, studies that were not used in mathematics, and studies that didn't meet other inclusion criteria of this study were excluded.

Figure 1

The Flowchart of the Literature Review Obtained According to the PRISMA Flow Diagram



Note. (Moher et al., 2009).

As a result of scanning the electronic databases indicated in Figure 1, a total of 188 studies, BMLK (*n*=34), BB (*n*=63) and Pre-K (*n*=91), were reached. After removal of 146 studies that did not meet the inclusion criteria or were duplicates, the remaining 42 studies were screened. The studies that used early intervention programs but did not address the effect on math skills, the studies that were conducted only qualitatively and the studies that were not written English or Turkish were excluded. Finally, 23 full text articles were evaluated for their eligibility and quality. Eleven studies that did not include required data for statistical calculations or relevant outcomes were excluded and the remaining 10 publications consistent with the inclusion criteria were included in the meta-analysis. The sample of this research consisted of 1081 participants from experimental (*n*=527) and control (*n*=554) groups.

Coding Method

Before statistical analysis of the studies involved in the research, a comprehensive coding form was developed to ensure the reliability and validity of this study. A coding form containing two parts as "study identity" and "study data" was prepared (see Table 5, Appendix 1). In the "study identity" part; author information, study year, study type, and the name of the intervention program were included, while the "study data" part included the application period, population size and effect size calculations.

To obtain the coding reliability value, two independent coders were asked to review all research separately and to enlist the results to the final evaluation form. After that, the conformity of the form was checked over by comparing the evaluations of the two coders. The inter-rater reliability between the coders was calculated according to Miles and Huberman's (1994) formula [number of agreements/(number of agreements+disagreements)X100] and found 100% agreement.

Data Analysis

The data to be used in the meta-analysis were inputted into a Microsoft Excel Spreadsheet for coding and tabulation. In addition to percentage and frequency calculations, through the CMA (3.0) software program (Borenstein & Rothstein, 1999), statistical values (effect sizes with corresponding confidence intervals, *p*-values, *Q*-value, and I^2 values), effect size calculations according to random and fixed effects models, heterogeneity calculations and publication bias calculations were performed (Bax et al., 2007). Cohen's (1992) standards suggesting that ≤ 0.20 is considered a 'small' effect size, 0.50 is a 'medium' effect size and ≥ 0.80 is a 'large' effect size, were used as guidelines to categorize effect sizes.

Heterogeneity and Effect Sizes

The control of heterogeneity is one of the basic steps of meta-analysis studies. The heterogeneity test reflects the variation in study outcomes that goes beyond what is expected between studies included in the meta-analysis (Deeks et al., 2021). The classical measure of heterogeneity test is Cochran's *Q* test distributed as the Chi-square ($\chi 2$) statistic with degree of freedom (k-1). The *Q* value obtained in the meta-analysis is compared with the chi-square value corresponding to the k-1 degree of freedom. The fact that *Q* value is greater than the value in the chi-square table is interpreted as the studies involved in the meta-analysis indicate heterogeneous distribution. In addition, the p value being less than 0.05 indicates that the effect sizes included in the analysis are heterogeneously distributed (Sullivan & Feinn, 2012). The heterogeneity test (*Q* test) is stated to be statistically significant in the use of large samples by many researchers (Gavaghan et al., 2000). Conversely, *Q* test has low power especially in studies performed with small samples (Higgins et al., 2003). Unlike *Q* statistic, I^2 statistic is not influenced by the number of studies and allows to comment on the amount of variance. I^2, representing the ratio of variance owing to systematic differences (Shadish & Haddock, 2009), gives a distinct result for heterogeneity and shows the total variance ratio of the effect size (Petticrew & Roberts, 2006). In other words, while *Q* test only provides information about the presence or absence of heterogeneity, it does not provide information about the extent of heterogeneity. Therefore, the I^2 statistic has recently been used to measure the degree of heterogeneity in a meta-analysis (Huedo Medina et al., 2006). Effect sizes are the standard measurement values used to specify the power and direction of the studies involved in the meta-analysis (Borenstein et al., 2009). Fixed effects model (FEM) and random effects model (REM) are employed to estimate effect sizes in the meta-analysis. FEM assumes that all studies in the meta-analysis share a common (real) effect size. The difference between studies is due to sampling error. In FEM, all factors that can affect effect sizes are similar across all studies, and therefore the real effect size is the same across all studies (Borenstein et al., 2009). REM presumes that all studies taking part in the meta-analysis have different real effect sizes. The difference between studies is not only due to sampling error but also due to the difference between studies (Field & Gillett, 2010). In cases where the researcher wants to generalize, REM is recommended especially in social sciences (Cumming, 2012; Field & Gillett, 2010). Due to heterogeneous distribution and being carried out in the field of social sciences, REM was taken into account in the interpretation of the effect sizes of the studies taking part in the present meta-analysis.

In meta-analysis studies, effect sizes belonging to intergroup differences are calculated with Cohen's d or Hedges'*g* formula (Borenstein et al., 2009). In the present research for the prediction of effect size, Hedges'*g* formula was used (Hedges & Olkin, 1985).

Results

Descriptive Data

The descriptive data of the studies are given in Table 1.

Table 1

Descriptive Data of the Studies in the Meta-Analysis

Study Variables		Frequency	Percent
Publication Year (k = 10)	2007-2014	2	20
	2015- 2021	8	80
Study Type (k = 10)	Doctoral Dissertations	2	20
	Research Articles	8	80
Intervention Program (k = 10)	BMLK	5	50
	BB	3	30
	Pre-K	2	20
Duration of the Experimental Process (k = 10)	6 weeks	2	20
	9 weeks*	1	10
	11 weeks	2	20
	One Semester	2	20
	One School Year	3	30
Age (k = 10)	36-72 Months	3	30
	48-72 Months	3	30
	60-72 Months	4	40

* Since there was only one study of 9 weeks, this study was not included in the analysis during the implementation period.

According to the descriptive data given in Table 1, there has been an increment in the number of experimental studies on the early mathematics skills of preschool children in the last 7 years. Of the studies, while 20% (*f*=2) were carried out between the years of 2007-2014, 80% (*f*=8) of them conducted between 2015 and 2021. On the other side, while 80% (*f*=8) of the studies were research articles, 20% (*f*=2) were doctoral dissertations. Of the studies, 50% (*f*=5) were regarding the use of BMLK, 30% (*f*=3) were BB and 20% (*f*=2) were Pre-K. According to the duration of the experimental process, it was determined that the time spent on the most experimental implementations was one school year (30%; *f*=3). This is followed by the 6 weeks (20%; *f* = 2), 11 weeks (20%; *f*=2) and one semester (20%; *f*=2) and 9 weeks (10%; *f*=1). With regard to age, while the most studies were conducted at the age range of 60-72 months (40%; *f*=4). Of the rest studies, 30 % (*f*=3) were carried out at the range of 36-72 months and other 30% (*f*=3) at the range of 48-72 months.

Heterogeneity Analyses

Heterogeneity analysis results of 10 studies are given in Table 2.

Table 2

Heterogeneity Analyses Results

Heterogeneity				Tau- Squared			
Q	df	*p*	I^2	τ^2	Standart Error	Variance	Tau
73.927	9	0.000*	87.826	0.345	0.203	0.041	0.587

*$p < .05$

As given in Table 2, the p value ($p<.05$), was first examined to evaluate the heterogeneity in the study and this result indicated that the 10 studies included in the analysis show heterogeneity with respect to effect size. *Q* statistic value conducted to determine homogeneity in meta-analysis studies was found to be 73.927. The effect size distribution was not homogeneous, since *Q* statistical value was observed to exceed the critical value of the chi-square distribution ($\chi 2(.05)=16.92$) at 9 degrees of freedom. On the other hand, I^2 value calculated for this study was 87.826 indicating a high level of heterogeneity. In accordance with the Higgins and Thompson (2002) classification, I^2 indicates 25% low, 50% medium, and 75% high heterogeneity. These results ($Q=73.927$, $p<.05$, $I^2=87.826$) show that the distribution is heterogeneous.

The Results of Analysis Models

Table 3 presents effect sizes of analysis models which are FEM as well as REM. In both approaches, all weighted effect sizes were significant than zero. In this research the *Q*-value is 73,927 and 9 degrees of freedom ($p<.001$). The result of alpha null hypothesis rejected and the true effect size is the same in all these studies. The I-squared statistic was found the value of 88%, which means some 88% of the variance in observed effects reflects variance in true effects. Because of these results REM was used in the current study.

Table 3

Results of the Overall Effect Size

Model type	*k*	Hedges'*g*	*SE*	95% Confidence Interval		*Z*	*p*	*Q*-*value*	*df*	I^2
				Lower	Upper					
FEM*	10	1.159	.067	1.09	1.29	17.413	.000	73.927	9	87.826
REM**	10	1.217	.203	.818	1.615	5.983	.000			

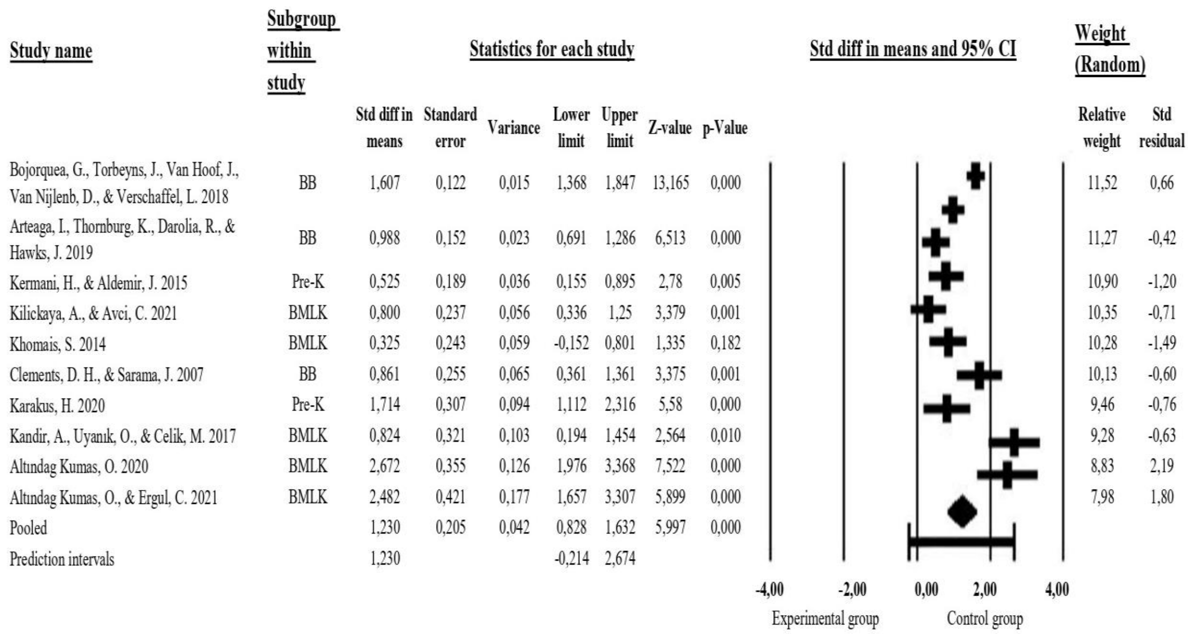
*Fixed Effects Model

**Random Effects Model

As given in Table 3, the overall effect size calculated according to REM was Hedges'*g*=1.217 with the standard error of .203. According to Cohen's (1992) classification, this effect size is a powerful positive value at a large level. For 95% of the confidence interval, the upper limit was 1.615 while the lower limit was .818. The test statistics results (*Z*=5.983, *p*<.001) revealed the statistical significance of the analysis. These results given in Table 3 indicate the existence of a positive, largely effective and significant (*p*<.05) effect in favor of using early intervention programs in developing preschoolers' or kindergartners' math skills. A forest plot for each of the studies taking part in the meta-analysis of the studies is given in Figure 2.

Figure 2

Forest Plot of the Studies



In Figure 2, the forest plot of the 10 studies within the scope of the meta-analysis includes Hedges'*g* effect sizes and confidence intervals of each study. Forest plots are a graphic interpretation of a meta-analysis results which denote studies with boxes and whiskers along a y-axis showing their effect size along the x-axis showing the lower and upper limits of the 95% confidence interval. When the 95% confidence interval from studies crosses the vertical line it means that intervention and comparator is not statistically significant and no effect on samples (Dettori et al., 2021). Weights are percentage values that indicates the individual study have how much influence on the overall effect. A summary point denoted with a diamond below the studies represents the overall pooled effect from the included studies. (Guddat et al., 2012). First of all, it whether there were outliers in the data set and it was determined that there were no outliers in the studies. 95% confidence interval of Khomais' study crosses the line of no effect and that is there is no clear differences between experimental and control groups in this study. Therefore, Khomais's study individually were not significant (p>.05). Other studies' 95% confidence interval do not cross the line of no effect and the result of these individual studies are significant (p<.05). In Figure 2, the pooled point estimate and 95% confidence interval lies entirely to the right of the line of no effect. Overall effect located at the bottom left which is .00 and 95% confidence intervals are .828 and 1.632. Since 95% confidence intervals do not cross the line of no effect and so the overall effect is significant (p<.05). The result show that there is a statistical difference in the outcome between groups and satisfaction favor the experimental group. While the widest range of confidence interval, with the effect size (Hedges'*g*=2.672) belonged to Altındag Kumas' study, the narrowest one (Hedges'*g*=.325) belonged to Khomais's study. Effect sizes of the studies are close to each other and overlap quite. Therefore, there is little to no study heterogeneity. Considering the weights of the studies, the result shows that the weight values are between 7.98 and 11.52. That is the influence of studies are individually similar on pooled result. In conclusion, as given in the forest plot, all the effect sizes of the studies have a positive effect that indicates the effectiveness of the use of early intervention programs is in favor of the experimental groups. Many variables involved intervention program play a role in the effectiveness of the intervention program mentioned above.

Moderator Analyses

Moderator analyzes can add a lot to meta-analyses as they provide clues as to the conditions that foster larger effects or for whom certain interventions may be more efficient (Bloch, 2014). Moderators in the current study include type of intervention program, the duration of the intervention, frequency of application and the participant's age (See Table 4). Due to the use of REM to assess overall effect sizes, heterogeneity test was performed to search the need for moderator analyses. Since the results confirmed the existence of heterogeneity the Q-value is 73.927 with 9 degrees of freedom and p<.001.

Table 4

The Results of Moderator Analyses

Moderators	Groups	Effect Size and 95% Confidence Interval				Test of Null		Heterogeneity		
		k	Hedge's *g*	Lower	Upper	*Z*-Value	*P* -Value	*Q*-value	df	*P*-Value
Type of Intervention program	BMLK	5	1.362	.509	2.216	3.128	.002			
	BB	3	1.173	.679	1.666	4.659	.000			
	Pre-K	2	1.082	-.063	2.227	1.852	.064			
	Tot. Betw. Overall	10	1.203	.803	1.604	5.894	.000	.191	2	.988
Implementation Periods	6 Weeks	2	0.627	.34	.914	4.282	.000			
	9 Weeks	1								
	11 Weeks	2	2.009	1.29	2.729	5.474	.000			
	One Semester	2	1.717	-.075	3.508	1.877	.06			
	One School Year	3	1.173	.679	1.666	4.659	.000			
	Tot. Betw. Overall	9	0.911	.679	1.144	7.679	.000	14.561	3	.002
Frequency of Application	Two or three days in a week	6	1.455	.863	2.047	4.819	.000			
	Every day in a week	4	0.902	.247	1.556	2.701	.007			
	Tot. Betw. Overall	10	1.206	.767	1.645	5.385	.000	1.512	1	.219
Age	36-72 Months	3	1.324	.423	2.225	2.879	.004			
	48-72 Months	3	0.936	.188	1.684	2.452	.014			
	60-72 Months	4	1.368	.758	1.978	4.395	.000			
	Tot. Betw. Overall	10	1.223	.805	1.642	5.726	.000	.830	2	.66

As given in Table 4, it was found that while studies used BB intervention program (*n*=3; Hedges'*g*=1.173, 95% CI [0.679, 1.666], *p*=.000) and Pre-K intervention program (*n*=2; Hedges'*g*=1.082, 95% CI [-0.063, 2.227], *p*=.064) had the smallest effect on mathematics learning outcomes, those used BMLK intervention program had the largest effect (*n*=5; Hedges'*g*=1.362, 95% CI [0.509, 2.216], *p*=.002) of the three programs. The overall effect size of all three programs were at a large level (Hedges'*g*=1.203) based on Cohen's (1992) classification. In addition, the inter-group homogeneity test results revealed that since the *Q* value (0.025) did not surpass the critical value of the chi-square distribution ($\chi 2(.05)=5.99$) at 2 degrees of freedom, the distribution was homogeneous. On the other side, no significant differences amongst the inter groups were detected (*p*=.988), indicating that these three programs don't have statistically significant overall effect sizes.

Studies with an implementation period of 11 weeks (*n*=2; Hedges'*g*=2.009, 95% CI [1.290, 2.729], *p*=.000) were found to have the largest effect while those with an implementation period of 4-5 week (*n*=2; Hedges'*g*=0.212, 95% CI [-0.157, 0.581], *p*=.261) had the smallest effect. Studies with an implementation period of 12-14 weeks (*n*=3; Hedges'*g*=1.377, 95% CI [0.325, 2.428], *p*=.010) and one school year (*n*=3; Hedges'*g*=1.173, 95% CI [0.679, 1.666], *p*=.000) had also large effect in accordance with Cohen's (1992) classification. On the other hand, those with an implementation period of two months (*n*=2; Hedges'*g*=0.627, 95% CI [0.340, 0.914], *p*=.000) had a medium effect. In addition, the overall effect size was Hedges'g=0.723 that is regarded as large based on Cohen's (1992) classification. When the intergroup homogeneity test was analyzed according to implementation periods, the *Q* value was found to be 24.757. Since this value was larger than the chi-square distribution ($\chi 2(.05)=9.488$) at 4 degrees of freedom, it can be said that the distribution was heterogeneous. A statistically significant difference (*p*=.000) in favor of both two or three days in a week and every day in a week.

Table 4 also shows the frequency of application of the intervention programs. Studies with the frequency of application two or three days in a week (*n*=6; Hedges'*g*=1.455, 95% CI [0.863, 2.047], *p*=.000) and every day in a week (*n*=4; Hedges'*g*=0.902, 95% CI [0.247, 2.701], *p*=.007). In addition, the overall effect size was Hedges'*g*=1.206 that is regarded as large based on Cohen's (1992) classification. When the intergroup homogeneity test was analyzed according to frequency of application the *Q* value was found to be 3.841. Since this value was larger than the chi-square distribution ($\chi 2(.05)=1.158$) at 1 degrees of freedom, it can be said that the distribution was heterogeneous. A statistically significant difference (*p*=.000) in favor of the 11-week implementation period (Hedges'*g*=2.009) was observed.

In age moderator analysis, although all studies have a large effect, studies that included those aged 36-72 months (*n*=4; Hedges'*g*=1.147, 95% CI [0.569, 1.726], *p*=.000) and those aged 60-72 months (*n*=5; Hedges'*g*=1.116, 95% CI [0.440, 1.791], *p*=.001) had larger effect than studies involving those aged 48-72 months (*n*=3; Hedges'*g*=0.936, 95% CI [0.188, 1.684], *p*=.014). Besides, the overall effect size was Hedges'*g*=1.083. This value was also at a large level based on Cohen's (1992) classification. The intergroup homogeneity test results according to age revealed that since the *Q* value (0.204) didn't exceed the critical value of the chi-square distribution ($\chi 2(.05)=5.99$) at 2 degrees of freedom, the distribution was homogeneous. No significant differences occured amongst the inter groups (*p*=.903), indicating that overall effect sizes of these three groups are not statistically different.

The Reliability of the Study

While carrying out meta-analysis, it is substantial to evaluate for publication bias, which expresses the relationship between statistically significant study results and the probability of publication (Sterne & Harbord, 2004). Sutton (2009) stated that ignoring the effect of publication bias could potentially lead to inflated results. In order to examine publication bias, a funnel plot was used. Funnel plots (see Figure 3) are scatter plots that plot effect sizes with respect to the standard errors or a precision statistic.

Figure 3

Funnel Plot to Detect Publication Bias

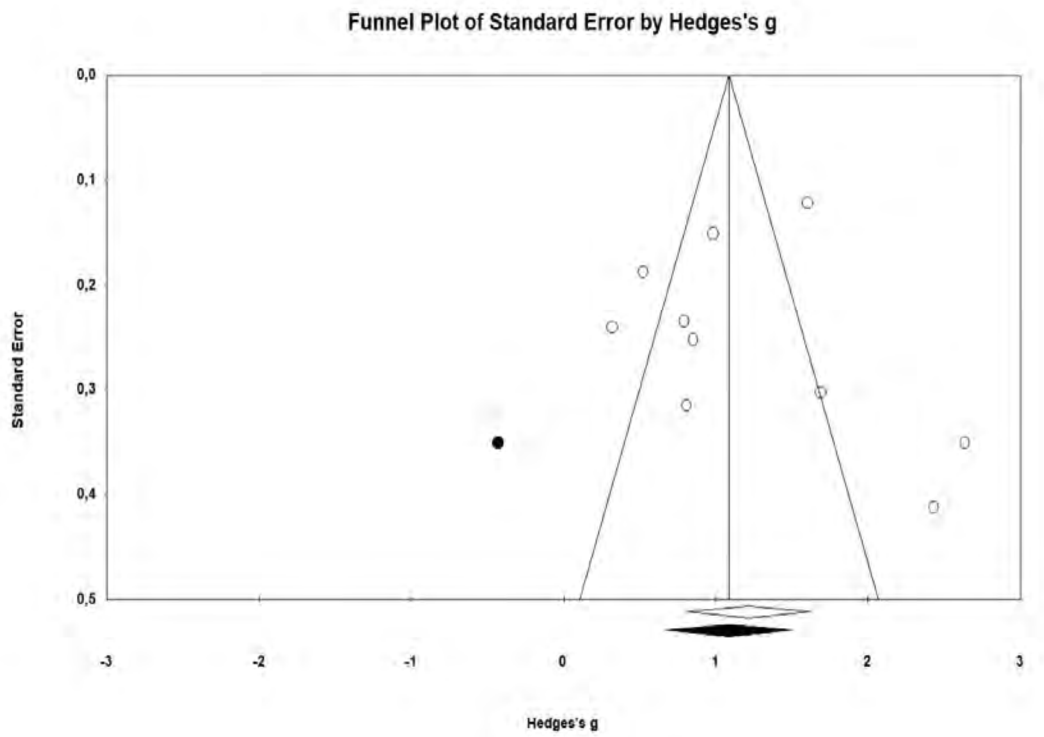


Figure 3 shows the visual inspection of the funnel plot. In this funnel plot, the majority of the plots are clustered symmetrically around the united effect size and towards the top of the plot. If publication bias does not occur, studies are anticipated to be distributed symmetrically around the combined effect size (Borenstein et al., 2009). If there is publication bias, then a higher concentration of studies belonging to smaller sample sizes will be seen at the bottom of the plot (Borenstein et al., 2009). The funnel plot indicates an outlier (Weber, 2009) and figure 3 shows that the funnel plot does not include the outlier. Therefore, it can be said that this funnel plot provides supportive evidence that publication bias is not a potential apprehension in the studies involved in the current research. In order to provide statistical tests to accompany the funnel plot, Egger et al. (1997), Begg and Mazumdar (1994) have developed tests that assess the relationship between sample size and effect size. Thus, each test is functionally similar to the funnel plot (Sterne et al., 2011). The results of Egger's regression tests conducted as a statistical method to test for asymmetry and bias were not statistically significant (95% confidence interval between -5.51333 lower limit and 6.70172 upper limit, Intercept=0.5942, t=0.22435 and p=.41405>0.5), showing that potential publication bias and asymmetry were not detected (Egger et al., 1997). According to Rothstein et al., (2005), "p value of 0.5 or less indicates that asymmetry is statistically significant" (p. 102). In Begg and Mazumdar (1994) test, the calculation of Kendall's tau b coefficient was made. The results (Tau b=.31; p=.105>.05) did not provide sufficient evidence of a positive correlation that exists in case of publication bias between effect size and variance. Consequently, Egger, Begg and Mazumdar values, which are not statistically significant, indicate that there is no publication bias (Sedgwick, 2013). A different approach to sensitivity analysis considers the 'fail-safe number' which was calculated to determine the extent to which publication bias could impact the entire results of the meta-analysis. The Fail-safe N ensures a statistic assessing the stability of study findings (Sutton, 2009). The Fail-safe N reports the number of additional studies, especially those that were unpublished or not significant that would nullify the results (Carson et al., 1990). Mullen et al. (2001) claimed that according to $N/(5k+10)$ formula if the result greater than 1 the likelihood of publication bias would be low. In line with $N/(5k+10)$ formula 1327/(5.10+10)=1327/60=22.12, which is greater than 1 and so the result indicated lack of publication bias. In Rosenthal (1979) claimed that if $N_R>5k+10$, the probability of publication bias would be decreased. The Fail-safe N pointed out that 16.479 studies were required to nullify the present study's findings. Given the confined research in early intervention programs and particularly, early math skills for young children, it is improbable that a notable number of unpublished studies will be available. Further, 16.479 additional studies to nullify the results indicates that there would be no possible changes in the findings from the present study, even if they are newly discovered studies (Sutton, 2009). Orwin's Fail-safe N was also calculated to address publication bias. Orwin's Fail-safe N attempts to quantify publication bias by determining the number of unpublished studies with the mean effect size of zero that is required to be incorporated into the meta-analysis before the mean effect size reduces to a trivial magnitude (Orwin, 1983). Based on the results of Orwin's Fail-safe N, 1158 more studies with a mean risk ratio of 0.001 are required to be added to the analysis before the pooled effect size becomes insignificant. For additional studies, when the effect size value is changed from null to 0.005, a minimum of 1158 studies are needed to bring the overall treatment effect to non-significance. These results may be inferred that the estimate is unlikely to be compromised by publication bias. Finally, to evaluate if publication bias was present, trim and fill method, based on estimating the number of missing studies in the study and the effect of these missing studies on the entire outcome (Duval & Tweedie, 2000), was performed. This method allows studies that do not have symmetrical counterparts on the opposite side of the effect size estimation to be trimmed from the analysis and then, provides backfilling of matching studies on either side of the mean to obtain symmetry in the distribution. No studies were trimmed or deleted from the analysis because this sensitivity analysis showed that no studies were missing. Under REM, the point estimate for the combined studies was 1.217(CI95% .818, 1.615). Under FEM, no studies were also missing and the point estimate for the combined studies was 1.159(CI95% 1.029, 1.29). Since trim and fill completes the funnel plot to assess publication bias, it is reasonable to assume there is a low possibility of publication bias in the present results.

Sensitivity analysis is another way to prevent publication bias. Vevea and Woods (2005) carried out sensitivity analyses to across a stable range of parameters rather than estimating these parameters. The sensitivity parameters in the model are a glaring remnant of its initial intent to estimate these parameters as opposed to doing sensitivity analysis across preset parameters (Hedges, 1992). Sensitivity analysis was used to reveal for the influence of outliers (Thabane et al., 2013) by using 'remove one study' procedure of the CMA (Aleknaviciute et al., 2023).

Figure 4

Sensitivity Analyses Results

Study name	Type	Hedges's g	Standard Error	Variance	Lower Limit	Upper Limit	Z value	p value	Weights
Bojorquea,	BB	1,607	0,122	0,015	1,368	1,847	13,165	0,000	11,52
Arteaga1, I.,	BB	0,988	0,152	0,023	0,691	1,286	6,513	0,000	11,27
Kermani, H.	Pre-K	0,525	0,189	0,036	0,155	0,895	2,780	0,005	10,90
Kilickaya,	BMLK	0,800	0,237	0,056	0,336	1,265	3,379	0,001	10,35
Khomais,S.,	BMLK	0,325	0,243	0,059	-0,152	0,801	1,335	0,182	10,28
Clements,D.	BB	0,861	0,255	0,065	0,361	1,361	3,375	0,001	10,13
Karakuş, H.,	Pre-K	1,714	0,307	0,094	1,112	2,316	5,580	0,000	9,46
Kandir, A.,	BMLK	0,824	0,321	0,103	0,194	1,454	2,564	0,010	9,28
Altindag	BMLK	2,672	0,355	0,126	1,976	3,368	7,522	0,000	8,83
Altindag	BMLK	2,482	0,421	0,177	1,657	3,307	5,899	0,000	7,98

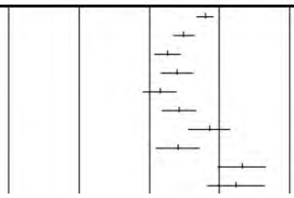
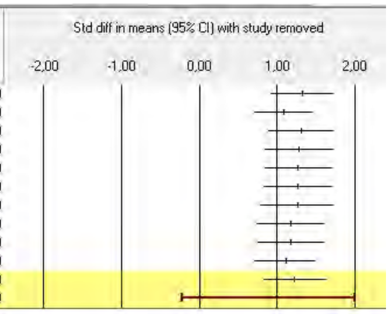


Figure 4 shows that how much weight was assigned to each study. Weights of studies are between 11.52 and 7.98. Any study exceeds more than 11 of the weight. That means any one study dominated the analysis. Every study gets at least 7% of the weight and so most of the studies played roles to predict to mean effect and heterogeneity. Therefore, basic conclusions are not depending on other studies.

Figure 5

The Results Effect Size When Studies Are Removed One By One

Model	Study name	Subgroup within study	Statistics with study removed						
			Point	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Khomais,S.,	BMLK	1,330	0,208	0,043	0,923	1,737	6,401	0,000
	Altindag	BMLK	1,084	0,192	0,037	0,707	1,460	5,642	0,000
	Kermani, H.	Pre-K	1,315	0,214	0,046	0,895	1,734	6,145	0,000
	Kilickaya,	BMLK	1,283	0,225	0,050	0,843	1,723	5,711	0,000
	Kandir, A.,	BMLK	1,274	0,221	0,049	0,841	1,706	5,772	0,000
	Clements,D.	BB	1,275	0,225	0,050	0,835	1,715	5,679	0,000
	Arteaga1, I.,	BB	1,269	0,241	0,058	0,796	1,743	5,255	0,000
	Bojorquea,	BB	1,182	0,221	0,049	0,749	1,615	5,354	0,000
	Karakuş,	Pre-K	1,180	0,218	0,048	0,753	1,608	5,407	0,000
	Altindag	BMLK	1,119	0,204	0,041	0,720	1,518	5,496	0,000
Random			1,230	0,205	0,042	0,828	1,632	5,997	0,000
Pred Int			1,230	0,000	0,000	-0,214	2,674	0,000	0,000



The study of Altındag Kumas is the highest effect size. The 10 studys' overall effect size is 1.23. When the study of Altındag Kumas removed the mean effect size is 1.20. That is the effect size of 10 studies which is 1.23 as same as the effect size of 9 studies which is 1.20. This shows that if the one study removed the effect size will not change significantly. Any study in this research does not show the impact of outlier because when one study removed the effect size do not change.

Conclusion and Recommendations

In this study, a meta-analytical examination was applied to reveal the effectiveness of early intervention programs (BMLK, BB and Pre-K) in developing early math skills of young children. The results showed that intervention programs have a positive effect in developing math skills of young children and the effect is at large level (Hedges'*g*=1.082). This significant and positive effect has provided consistent result with the effect coefficients of the studies included in the analysis, which revealed that the effectiveness of early intervention programs on math achievement was in favor of the experimental group (i.e., Altındag Kumas, 2020; Altındag Kumas & Ergul, 2021; Arteaga et al., 2019; Bojorquea et al., 2018; Celik & Kandir, 2013; Clements & Sarama, 2007, 2008; Kandir et al., 2017; Khomais, 2014; Kilickaya & Avci, 2021; Papadakis et al., 2017). This result is also consistent with the results of the studies that were excluded from the analysis (i.e., Ginsburg & Audley, 2020; Hamilton & Liu, 2018; Mwaura et al., 2008; Presser et al., 2015; Scalise et al., 2017; Sollom, 2021; Zippert et al., 2021). Similarly, this result coincides with the meta-analysis studies revealing the effect of early intervention programs on math achievement. For example, Codding et al. (2009) examined specific interventions that could be used with students identified as needing additional support in mathematics. The results revealed that these interventions were effective and had a large effect size. Another meta-analysis results by Codding et al. (2011) on mathematics fluency suggested that drill and practice with modeling produced the largest effect sizes. In Kroesbergen and Van Luit's (2003) meta-analysis study regarding mathematics interventions for elementary special needs students, the results yielded a large effect size indicating that the interventions were effective. Mononen et al. (2014) conducted a meta-analysis regarding early numeracy interventions in children aged four- to seven-years old at risk for math difficulties and included 19 peer-reviewed studies in their analysis. The interventions showed, to various degrees from moderate to large, the promoted effect in improving the early numeracy skills in at-risk children. The study by Malofeeva (2005), the only meta-analysis to address the mathematics learning of preschool and kindergarten children, yielded that on average, early mathematics instruction was effective for all intervention types and students.

On the other hand, according to the results of moderator analyses, a statistically significant difference was found in implementation periods. The highest overall effect size was observed in the 11-week implementation period (g = 2.009). Similarly, in Altındag Kumas and Ergul's (2021) and Karakus' (2020) studies, the time allocated for application of early intervention programs was limited to 11 weeks to assess early mathematical development of young children. In terms of type of intervention program and age variables, no significant differences were observed. In this regard, the meta-analysis results by Malofeeva (2005) indicated that none of the variables of the study such as number of weeks of treatment, age, and type of design were significant predictors. Considering the developments of children, it is thought that the effectiveness of very long-term programs decreases. In addition, when the content of the 11-week study, which was found to be effective as a result of the research. The program is more effective than 1 semester and 1 school year due to the fact that the application intensity is higher than the others. Researches assume that the intensity of intervention significant role on effectives of intervention programs rather than duration of intervention (Coban et al., 2023).

Although a number of studies have been conducted on the efficiency of early intervention programs on math achievement of young children, the meta-analytic review of these primary studies is quite limited. Most of these studies have focused on children diagnosed with learning difficulties or mental retardation. However, although this study has addressed normally achieving young children, it has some limitations. One considerable limitation is that only the studies involving any of the three early intervention programs of BMLK, BB, and Pre-K were included in the current meta-analysis. In this regard, studies that examined the effectiveness of these early intervention programs were included. Second limitation is that this study focused on math skills rather than effective educational techniques used. Additionally, only the use of these programs in the studies was taken as a basis, without limiting the use of a specific data collection tool. Third limitation is that early math skills were addressed here as counting, comparison, classification, enumeration, computation, and measurement skills expressed in the studies within the scope of this meta-analysis. Therefore, estimation, writing numerals, geometry and fractions were not emphasized. One more limitation is that studies that include the development of language skills as well as early math skills and that compare the development of these two skills were excluded. The last limitation is that the current study carried out type of intervention program, the duration of the intervention, and the participants' age as moderators. More various moderators can be considered in future studies.

Implications

The outcomes of the current study provided an evidence of the effectiveness of early intervention programs on math skills. No notable differences were found among the early intervention programs and age groups considered in this study. However, a significant difference was found in favor of the 11-week implementation period. It is possible to include some implications for future research within the scope of this synthesis. Although early intervention studies in math with younger children do exist, relatively few studies have focused on enhancing the early math skills of normally achieving young children. Therefore, more empirical research of early intervention on normally achieving young children are required in the future. The intervention programs may have planned according to short term rather than one semester and one school year. This creates advantages in terms of saves time, resources and workforce. Although meta-analyses regarding the effects of math interventions on school age students are available, there are hardly any meta-analyses addressing early intervention programs for enhancing preschool and kindergarten children's math skills. In this regard, more early intervention meta-analyses to promote the learning of this age group and to meet their needs in acquiring important skills such as math or language skills is needed in the future. On the other hand, future meta-analysis research may compare the contribution of early intervention programs to the development of math skills in children of this age group with their later achievement in the first or second grades of primary school.

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Statement of Responsibility

Conceptualization: [Ensar Yıldız]; Methodology and validation: [Şenel Elaldı & Ensar Yıldız]; Formal analysis and investigation: [Şenel Elaldı & Ensar Yıldız]; Writing - original draft preparation: [Özge Koca]; Writing - review and editing: [Özge Koca]; Supervision: [Şenel Elaldı]

Conflicts of Interest

No potential competing interest was reported by the authors.

Author Bios:

Ensar Yıldız: Ensar Yıldız graduated from Sivas Cumhuriyet University Elementary Education in 2013. He received a bachelor's degree in preschool education from Sivas Cumhuriyet University in 2015. He completed Master of Science in

Classroom Education in 2018. He was a student of Integrated Ph.D. and scholarship holders at 100/2000 Council of Higher Education (CoHE) Integrated Doctoral Scholarship Programme in preschool education at Hacettepe University between 2018 and 2019. He completed Integrated Ph.D in 2022. Since 2023, he has been working as an assistant professor in the Department of Preschool Education, Faculty of Education, Sivas Cumhuriyet University, and since 2024, he has been serving as the associate dean. He has studies on mathematics, metacognition, language and concept development, early literacy, values education, outdoor learning environment on early childhood education.

Özge Koca: Özge Koca received a bachelor's degree in preschool education from Boğaziçi University. She completed non-thesis master's degree program in Educational Measurement and Evaluation at Hacettepe University. She is a student of Integrated Ph.D. and scholarship holders at 100/2000 Council of Higher Education (CoHE) Integrated Doctoral Scholarship Programme in preschool education at Hacettepe University since 2018.

Şenel Elaldı: Şenel Elaldı works as a professor in Curriculum and Instruction Program in the Department of Educational Sciences in the Faculty of Education of Sivas Cumhuriyet University. She completed her PhD education in Curriculum and Instruction Program in the Department of Educational Sciences in the Faculty of Education of Fırat University. She has worked in the Department of Educational Sciences of the same faculty for ten years. She is interested in curriculum and instruction, teacher training and thinking skills.

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Note: *One asterisks (*) was used for the studies involved in the meta-analysis.*

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