Early Numeracy and Mathematics Development:

A Longitudinal Meta-analysis on the Prediction Nature of Early Numeracy

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Liu Yuting initiated this project, collected and coded the data, conducted all the analyses, and drafted the paper. Peng Peng supervised the whole project, came up with the theoretical framework, rewrote/edited the Introduction and Discussion of the paper. Yan Xueye double coded the data.

Abstract

In this meta-analysis of 54 longitudinal studies with over 58,000 students in grades K–12, we examined the predictive nature of early numeracy measured at or before the first year of formal schooling in relation to later mathematics. Results showed that early numeracy significantly predicted mathematics measured after six months or later, r = .49, 95% CI [.47 .52]. After controlling for all moderators in a model, results indicated that (a) different early numeracy including numbering, relations, and arithmetic operations did not differ much in their predictions of different later mathematics; (b) early numeracy as a whole was more predictive of later advanced mathematics skills (word problems) than of later foundational mathematics skills (calculations and fact fluency); (c) early numeracy's prediction of later mathematics was stronger with longer prediction intervals; and (d) the earlier early numeracy was assessed, the stronger its prediction of later mathematics. Together, these findings suggest that early numeracy may be a unitary construct. Early numeracy does not merely serve as a steppingstone with temporary effects on foundational mathematics; instead, it likely triggers a snowballing effect, cumulatively influencing mathematics development over time.

Keywords: early numeracy, mathematics, longitudinal, steppingstone, snowballing

Educational Impact and Implications Statement

This work shows that early numeracy may be a unitary construct and its influence on mathematics development is accumulative in nature. Instruction on a comprehensive set of early numeracy skills before formal schooling may exert a long-term and positive impact on mathematics development.

Early Numeracy and Mathematics Development: A Longitudinal Meta-Analysis on the Predictive Nature of Early Numeracy

Mathematics is crucial for individual development, providing essential knowledge for daily life and the foundation for learning science, technology, and engineering in school (Claessens & Engel, 2013; Heckman et al., 2018; M. C. Long et al., 2012; National Council of Teachers of Mathematics, 2006; National Research Council, 2009). Not surprisingly, educational policies across countries emphasize early instruction in mathematical abilities; examples include the development of school-age mathematics standards in the U.S. (National Council of Teachers of Mathematics, 2000), the Draft of the Preschool Education Law of the People's Republic of China (Draft for Solicitation of Comments; Ministry of Education of the People's Republic of China, 2020), and the Council Conclusions on preparing young people for the 21st century: An agenda for European cooperation on schools (European Commission, 2008).

Early numeracy is the initial set of mathematics skills children learn, and forms the foundation for mathematics learning (Aunio, 2019; Aunola et al., 2004; Geary et al., 2018; Jordan et al., 2010; Purpura et al., 2013). Indeed, many longitudinal studies demonstrated that early numeracy predicted mathematics performance in the elementary stage (Aunola et al., 2004; Desoete & Grégoire, 2006; Friso-van den Bos et al., 2015; Geary et al., 2012; Krajewski & Schneider, 2009; Missall et al., 2012; Morgan et al., 2009; Nguyen et al., 2016), in middle school (Bailey et al., 2014; Davis-Kean et al., 2022; Korpipää et al., 2017, 2020; Mazzocco & Grimm, 2013; Watts et al., 2014), and even in college (Davis-Kean et al., 2022).

However, two major sets of questions remain to be answered regarding the predictive nature of early numeracy for later mathematics.

First, it remains unknown whether various early numeracy skills (i.e., numbering, relations, and arithmetic operations) measured at or before the beginning of formal schooling differentially predict different later mathematics skills. Answers to this question help us understand the structure of early numeracy—Is it a unitary or a diverse construct (Aunio et al., 2004, 2006; Clements et al., 2008; Jordan et al., 2006; Purpura & Lonigan; 2013)? Second, does the predictive validity of early numeracy for later mathematics change over time (Clements & Sarama, 2020)? Answers to this question help us understand whether the effects of early numeracy on later mathematics are constrained within a relatively short timeframe or long-lasting.

The present longitudinal meta-analysis aimed to answer these two questions. With meta-analysis, we can pool data from many studies to create a large sample size, thereby enhancing the reliability and robustness of the conclusions drawn. More importantly, with meta-analysis we can control for/explore various confounding/moderating variables. This allows for a better understanding of the between-study heterogeneity that contributes to mixed findings in the literature, a challenge not readily tackled by individual empirical studies. In the following, we discuss our theoretical and methodological approach in detail.

Unitary or Diverse Nature of Early Numeracy?

For a long time, there is a debate on whether early numeracy is a unitary construct (Clements et al., 2008; Dierendonck et al., 2021; Thomas et al., 2023) or a diverse construct (Aunio et al., 2004, 2006; Jordan et al., 2006; Purpura & Lonigan; 2013). The outcome of this debate holds significant consequences for shaping both curriculum content and assessment methods. If early numeracy is unitary, a more integrated instructional approach might be effective. Otherwise, curricula and interventions may need to target specific types of early numeracy separately. Moreover, tailoring assessments to measure children's early numeracy skills depends on recognizing whether these skills form a single construct or multiple constructs. In the following, we briefly reviewed findings from two major approaches investigating the structure of early numeracy: Factor analysis and longitudinal analysis.

Factor Analyses of the Early Numeracy Construct

Some suggested that early numeracy may be a unitary construct. For example, in data from 360 low- and middle-income preschoolers (mean age 4 years), Clements et al. (2008) found that various early numeracy skills adequately fit a one-factor model. In a sample of 167 French kindergarten children (mean age 5.17 years), Thomas et al. (2023) found that various early numeracy skills fit a single-factor model better than a two-factor model (numeral knowledge and informal numeral knowledge). In a sample of 644 prekindergarten and kindergarten children (4 to 6 years old), Dierendonck (2021) found that despite the presence of specific factors such as counting, relations, and arithmetic, early numeracy was mainly underpinned by a general factor.

Some suggested that early numeracy was a two-factor construct. In 2000, the U.S. National Council of Teachers of Mathematics (NCTM) proposed a model with two factors for early numeracy: “numbering” and “relations”. *Numbering* refers to the ability to understand the rules and processes of counting sequences, such as cardinality, one-to-one correspondence, counting error, numeral identification, subitizing, and estimation (Charitaki et al., 2021; Nelson & McMaster, 2019; Purpura & Lonigan, 2013). *Relations* involve the ability to understand relationships between items (sets or numbers), such as in quantity matching, recognition of missing numbers, number line estimation, quantity discrimination, and enumeration of ordinal numbers (Charitaki et al., 2021; Purpura & Lonigan, 2013). Aunio and colleagues (Aunio et al., 2006) reported that this two-factor structure, comprising numbering and relations, provided a better fit than did a one-factor structure in data collected from 333 Chinese and Finnish typically developing preschoolers (mean age 6 years). Jordan et al. (2006) proposed a different two-factor model of early numeracy, consisting of numbering (as proposed by the NCTM, 2000) and “arithmetic operations”, with the latter representing an understanding of the composition and decomposition of sets of objects or numbers, including addition or subtraction with or without objects, story problems, and place values (Nelson & McMaster, 2019; Purpura & Lonigan, 2013). Jordan et al. identified this two-factor model as the best model in 411 U.S. low- and middle-income kindergartners (mean age 5.8 years).

The U.S. National Research Council (NRC, 2009) suggested an umbrella three-factor early numeracy model comprising numbering, relations, and arithmetic operations (cf. Charitaki et al., 2021; Purpura & Lonigan, 2013, 2015). This three-factor model implicates a potential sequential relationship among the three factors. Numbering lays the foundation for the development of relations; relations, for the development of arithmetic operations. In 393 typically developing U.S. children aged 3 to 6 years with low to middle socioeconomic status, Purpura and Lonigan (2013) found that the three-factor model gave the best fit in comparison with all other two-factor and one-factor models. However, those authors also observed that the three factors were highly related (Aunio et al., 2006; Jordan et al., 2006; Purpura & Lonigan, 2013), so that the construct of early numeracy might be unitary yet diverse in nature.

Longitudinal Analyses of the Early Numeracy Construct

Another approach to explore the structure of early numeracy is based on predictive criterion validity in longitudinal studies to determine how various early numeracy skills predict various later mathematics skills (Lamb et al., 2002; Josenby et al., 2009; McManus et al., 2013; Pisani et al., 2022). The rationale is that if different early numeracy skills differentially predict different later mathematics skills, early numeracy may be considered a diverse construct. Otherwise, early numeracy may be considered a unitary construct.

However, empirical findings are mixed on the relations between different types of early numeracy skills and different later mathematics skills. Nguyen et al. (2016), for example, found that numbering in kindergarten was the strongest predictor of comprehensive mathematics achievement in the fifth grade. Missall et al. (2012) suggested that relations may be most important for later mathematics development—that relations in kindergarten and first grade were more predictive of third-grade comprehensive mathematics achievement than numbering was. Other studies indicated that arithmetic operations in kindergarten may be the strongest predictor of fifth-grade comprehensive mathematics outcomes in comparison with numbering and relations (Fuhs et al., 2016; Locuniak & Jordan, 2008; Nguyen et al., 2016; Träff et al., 2020; Wong & Chan, 2019).

Predictive Nature of Early Numeracy

The other important and yet unaddressed question is whether the relation between early numeracy and later mathematics vary with the prediction intervals or the initial measurement time of early numeracy, which is related to two hypotheses about the predictive nature of early numeracy.

Steppingstone hypothesis

Within a given domain, people develop skills from the foundational and constrained, which are easy to master, to the more complex and unconstrained, which are more difficult to master. In physical development, for example, children typically progress from foundational and constrained skills such as rolling and crawling to relatively complex skills such as walking and running. In language development, individuals proceed from crying to cooing, babbling, using single sounds, blending sounds, producing words, and eventually the speaking of complex phrases. Each skill serves as a steppingstone for the next, highly correlated with the preceding one; and this process is often referred to as the *steppingstone effect* (Bunk, 1991; Clark, 2007; Stuart & Coltheart, 1988).

Children's academic development shows similar patterns. Reading development, for example, involves sequential mastery of skills, with children first acquiring phonological awareness (a constrained skill, relatively easy to master) before progressing to word reading, sentence reading, and ultimately, complex reading comprehension (Ehri, 2020). Kjeldsen et al. (2014) revealed that phonological awareness in Grade 1 had a positive impact on word reading in Grade 3, but the impact of phonological awareness diminishes beyond this stage, exerting no influence on more advanced reading skills in later grades, which supports the steppingstone hypothesis of phonological awareness for reading development.

Similarly, in mathematics, children's cognitive development follows specific developmental paths, known as Learning Trajectories (Sarama & Clements, 2009). That is, mathematics development begins with the acquisition of foundational and constrained skills such as early numeracy and calculations and advances to more complex skills such as word problem solving and algebraic thinking. Accordingly, the influence of early numeracy on mathematics development may follow the steppingstone hypothesis such that early numeracy may be more closely related to foundational mathematics skills that draw relatively fewer cognitive resources to master such as calculations (Peng et al., 2019), and the effects of early numeracy on later mathematics may be relatively temporary (e.g., starting out as a smooth progression and then trending downward with development).

There is empirical evidence supporting the steppingstone hypothesis of early numeracy. For example, some found that early numeracy was related mostly to fact fluency and calculations but not to word problems during the elementary stage (Nunes et al., 2012; Zhang et al., 2016). Some suggested that numbering (e.g., counting) as the strongest predictor of later fact fluency and calculations (Desoete et al. 2009; Koponen et al. 2018; Long et al. 2016). Moreover, some demonstrated that the correlation of each early numeracy subtype with later advanced mathematics decreases with development (Burland, 2011; Jordan et al., 2009; Träff et al., 2020; Watts et al., 2014; Zhang et al., 2020).

Snowballing Trigger Hypothesis

Early numeracy as a predictor of later mathematics may also reflect a snowballing mechanism, characterized by a developmental cascade in which initial advancements in a specific area gradually gain momentum, leading to more substantial growth and proficiency over time (Masten, 2003).

Although early numeracy is a relatively constrained skill, its impact on later mathematics may be accumulative. When students have a faster and better mastery of early numeracy, they are more likely to retrieve early numeracy knowledge to facilitate the learning of sequentially close and similar calculation skills (Cirino et al., 2018; Jordan et al., 2009; D. Zhang et al., 2020). Better development of calculations may be more likely to support the learning and development of more advanced mathematics that are procedurally complicated and draws more cognitive resources such as word problems and algebra (Cirino et al., 2018; Desoete et al., 2012; Fuchs et al., 2012; Jordan et al., 2013; Peng et al., 2016, 2019; Rittle-Johnson et al., 2017). Over time, the impact on mathematics resulting from early individual differences in early numeracy may increase throughout mathematics development (Maerton, 1968). In other words, early numeracy as a predictor could be a snowballing trigger for mathematics development, and these snowballing effects may become stronger with time as they affect more advanced mathematical skills. Accordingly, the timing of learning early numeracy in early childhood is crucial; the earlier that students master early numeracy, the more likely they will be to acquire sequentially similar mathematical skills and in turn perform better on later advanced mathematical skills.

Some empirical studies provided support for the snowballing trigger hypothesis of early numeracy. For example, some suggested that in comparison with typically developing peers, kindergarteners with difficulties in early numeracy often develop mathematics at a slower rate in the elementary grades (Aunola et al., 2004; Geary et al., 2012; Morgan et al.

2009; Purpura & Lonigan, 2015). Early numeracy remains highly predictive of comprehensive mathematics achievement for students at age 13 (Koponen et al., 2019; Mahdavi, 2017; Mazzocco & Grimm, 2013) and of word problems for students at age 15 (Davis-Kean et al., 2022). Moreover, some suggested that the relations between early numeracy and later mathematics increases with time (Lee et al., 2016; Schneider et al., 2018).

Prior Meta-Analysis Studies

There are several meta-analyses of early numeracy intervention effects, for low-performing young children (Charitaki et al., 2021) and for typical developing children in preschool through the early elementary grades (Nelson & McMaster, 2019). These studies showed that early numeracy interventions are moderately effective (g = 0.61 for low-performing young children, g = 0.64 for typical developing children) in improving mathematics outcomes, and that early numeracy interventions with shorter durations have a larger effect. For subtypes of early numeracy, Nelson and McMaster (2019) found that intervention with numbering content had the largest effect size, followed by intervention with relations and arithmetic operations. Charitaki et al. (2021) found that interventions with numbering and relations showed a larger effect size than did interventions with arithmetic operations. However, neither meta-analysis statistically tested differences in the effectiveness of these early numeracy subtype interventions.

Apart from intervention-focused meta-analysis studies, Schneider et al. (2018) conducted a correlational meta-analysis in which they found a moderate relationship between number line and mathematics in general (r = 0.44), and this correlation increased from age 4 to age 14. However, they focused primarily on concurrent associations between a specific early numeracy skill (number line representations) and overall mathematics, rather than exploring longitudinal correlations between various early numeracy skills and various mathematics skills.

Other Moderators

Thus, prior empirical studies and meta-analysis studies yielded mixed findings for whether various types of early numeracy predict different later mathematics skills differently, and for whether early numeracy's prediction of later mathematics follows the steppingstone hypothesis or the snowballing trigger hypothesis. These mixed findings are not only related to the types of early numeracy and later mathematics skills (as mentioned above) but may also be due to other moderators or confounding variables including initial age (initial time points for measuring early numeracy as a predictor), prediction intervals, and student learning status.

Initial Age

Children's age for learning early numeracy is broad, usually ranging from 3 to 7 years (Education Commission of the States, 2018; Nelson & McMaster, 2019). Structurally, early numeracy is relatively simple before kindergarten, consisting of counting from 1 to 10, identifying the cardinal meaning of numbers up to 3, and comparing non-symbolic numbers (Casey et al., 2018; Raghubar & Barnes, 2016), skills often considered as steppingstones for later mathematics (Aunio, 2019; Aunola et al., 2004; Geary et al., 2018). With development and schooling, the complexity, diversity, and variation of early numeracy increase, which likely increases early numeracy's predictive ability for later mathematics (Anders et al., 2012; Aunio & Niemivirta, 2010; Van Luit & Schopman, 2000).

Prediction Intervals

The prediction interval is the interval between the initial time point of measuring early numeracy and the later time point of measuring mathematics. Given the steppingstone hypothesis, a shorter prediction interval should lead to early numeracy's stronger prediction of later mathematics. Given the snowballing trigger hypothesis, a shorter prediction interval should lead to early numeracy's weaker prediction of later mathematics. There are also possible interactions between the initial age for measuring early numeracy and prediction intervals. Based on the steppingstone hypothesis, early numeracy measured at an earlier time with a shorter prediction interval should have a stronger prediction of later mathematics, in comparison with early numeracy measured at a relatively later time with a longer prediction interval. In contrast, based on the snowballing trigger hypothesis, early numeracy measured at an earlier time with a longer prediction interval should have a stronger prediction of later mathematics, in comparison with early numeracy measured at a relatively later time with a shorter prediction interval.

Learning Status

Students with mathematics learning disabilities often show lower early numeracy performance but faster development of early numeracy than do typically developing students (Aunio, 2019; Aunio & Niemivirta, 2010; Desoete et al., 2009; Jordan et al., 2006; Raghubar & Barnes, 2016). In addition, early numeracy performance is often more heterogeneous in students with mathematics learning disabilities than in typically developing students (Moll et al., 2015; Morgan et al., 2009). Thus, it is likely that the prediction of early numeracy for later mathematics is stronger in students with mathematics learning disabilities than in the typically developing students.

Aims

To sum up, the present meta-analysis aimed to answer two research questions. First. what are the longitudinal correlations between early numeracy measured at and/or before the first formal schooling year and mathematics measured six months apart or later? Second, is the relation between early numeracy and later mathematics moderated by subtypes of early numeracy, types of later mathematics, initial age of early numeracy measurement, prediction intervals, and student learning status?

We hypothesize that early numeracy should significantly predict later mathematics. If early numeracy is a unitary construct, various types of early numeracy should predict a specific type of later mathematics to a similar degree, and a specific subtype of early numeracy should predict different later mathematics to a similar degree. If early numeracy is a diverse construct, various types of early numeracy subskills should predict a specific type of later mathematics differently. A specific subtype of early numeracy should predict different types of later mathematics differently.

Given the steppingstone hypothesis, early numeracy may show a stronger prediction of foundational mathematics such as fact fluency and calculations than of advanced mathematics such as word problems and algebra. Early numeracy's prediction of later mathematics may decrease with prediction interval (see Figure 1a), and a later early numeracy measurement time point may be related to a stronger prediction of early numeracy for later mathematics. In contrast, given the snowballing trigger hypothesis, early numeracy may have a stronger prediction of advanced mathematics than of foundational mathematics. Early numeracy's prediction of later mathematics may show a nonlinear upward trend (see Figure 1b), with stronger predictions associated with longer prediction intervals, and the earlier early numeracy measurement time point may be related to a stronger prediction of early numeracy for later mathematics.

Methods

Literature Search

This review includes studies published from January 1990 to May 2022 in which a longitudinal design was used to focus on early numeracy's prediction of later mathematics. We chose 1990 because it was one year after the release of the National Council of Teachers of Mathematics curriculum standards in 1989, which also was a year earlier than the development of early mathematics curriculum standards in most other countries. We first searched the Education Resources Information Center (ERIC), Medline, and PsycINFO databases with the following search terms: (math*) AND (longitudinal OR growth OR predict* OR traject*) AND (numeracy OR cardinality OR counting OR number OR comparison OR "quantity discrimination" OR early OR preschool OR preparatory OR preK OR Kindergarten OR childhood); the asterisk enables inclusion of different forms of search terms (e.g., predict* can include *prediction* and *predictors*). We then conducted a forward and backward search based on prior meta-analyses related to early numeracy and searched unpublished articles from the Dissertation and Masters Abstract indexes in the ProQuest Database. Last, we reached out to researchers to request correlation tables not found in their published reports.

Inclusion Criteria

The initial search yielded 1,915 studies. After excluding 138 replicates and 1,362 nonrelevant studies, we screened the full texts of the remaining 415 studies for the following inclusion criteria (see Figure 2):

1. The authors examined a longitudinal trajectory of mathematics achievement in which mathematics measurements were administered at two different times at least six months apart.
2. The study's first measurement of mathematics performance occurred before formal schooling or in the first year of formal schooling (Education Commission of the States, 2018; Nelson & McMaster, 2019). Due to different countries' definitions of schooling before formal schooling (i.e., preschool in the U.S., Canada, England, and Australia; kindergarten in China, Singapore, Sweden, Finland, Belgium, Norway, Italy, German, and Turkey) and the first year of formal schooling (i.e., kindergarten in the U.S., Canada, England, and Australia; G1 in China, Singapore, Sweden, Finland, Belgium, Norway, Italy, German, and Turkey), we determined inclusion according to the time of the first measurement corresponding to the participants' nationality. If the study did not specify formal schooling years, we used 6.5 years as the cutoff age for the first formal schooling.
3. The study's second measurement of mathematics performance occurred after first-year formal schooling (after the age of 6.5 years).

4. The mathematical content for the study's first measurement included early numeracy, and this assessment either focused on one specific type of early numeracy or encompassed all three types.
5. The authors used objective tests to measure mathematics achievement.
6. The study provided data for the calculation of effect sizes, such as direct bivariate correlations between initial and later mathematics measurements, or simple regression with early numeracy as the only predictor of later mathematics performance.
7. Studies with only subjective measures of mathematics performance via parents' or teachers' ratings were excluded, and single-subject, single-group, qualitative, and case study designs were excluded.

Coding

We coded the information within two broad categories: participants' characteristics and information about mathematics measurement.

Participants' Characteristics

Gender. We reported gender as the percentage of male participants.

Age. We coded students' age at early numeracy measurement and for later mathematics. If a study did not report age, based on the average age of compulsory schooling for students entering each grade in the U.S. (Education Commission of the States, 2018), we coded average age given the grade levels reported in the study. Average age was as follows: kindergarten (5.5 years old), Grade 1 (6.5 years old), Grade 2 (7.5 years old), Grade 3 (8.5 years old), Grade 4 (9.5 years old), Grade 5 (10.5 years old), Grade 6 (11.5 years old), Grade 7 (12.5 years old), Grade 8 (13.5 years old), Grade 9 (14.5 years old), Grade 10 (15.5 years old), Grade 11 (16.5 years old), Grade 12 (17.5 years old). In coding, we transformed the grade into age for only four studies.

Prediction Intervals. To code prediction intervals in the studies, we used the age difference between the measurement of early numeracy and subsequent mathematics assessments as the prediction interval.

Sample Learning Status. We divided learning status into typically developing students and students with mathematics learning disabilities. If the study did not report students' type, we coded this as typically developing students.

Mathematics Measurement

We documented the full names of the mathematics measurements. If a study measured only one dimension on a scale, such as Applied Problems on the Woodcock-Johnson III Tests of Achievement (Woodcock et al., 2001), we coded the full name of the scale and its sub-dimension.

Subtypes of Early Numeracy. Based on the three-factor model (Charitaki et al., 2021; National Research Council, 2009; Purpura & Lonigan, 2013), we coded early numeracy as consisting of the factors *numbering*, *relations*, and *arithmetic operations*. If an early numeracy measure was indexed by all three subtypes, we coded it as comprehensive early numeracy. We did not include early numeracy measure was indexed by two subtypes.

Subtypes of Later Mathematics. Based on the Common Core State Standards (CCSS, 2010) for mathematics and related mathematics meta-analysis studies (Peng et al., 2016; Powell et al., 2013), we categorized mathematics outcomes as follows: early numeracy, fact fluency, word problems, calculations, algebra, and geometry. Factual fluency is a fundamental mathematics skill that entails mastering sums between 0 and 10 so that students can arrive at accurate, timely answers. Calculation encompasses multidigit addition, subtraction, multiplication, and division. Word problems involve the ability to understand the problem's narrative, focus on relevant and ignore irrelevant information, construct a number sentence, and solve for the missing number to find the answer. Algebra consists of problems that can be solved by pre-learned symbol manipulation algorithms taught in many algebra curricula. Geometry involves questions of shape, size, relative position of figures, and the properties of space. If the mathematics outcome from a study included two or more of these domains, we code them as comprehensive mathematics outcomes.

Coding Reliability

The first and third authors independently coded the included studies. We divided the number of agreements by the total number of coded elements and multiplied by 100 to obtain coding reliability; this yielded 98.06 % agreement across all coded items, with 97.4% for numbering, 98.2% for relations, 96.2% for arithmetic operations, 96.8% for comprehensive early numeracy skills, 97.9 % for early numeracy, 98.6% for fact fluency, 97.5% for word problems, 96.4% for calculations, 100% for algebra, 100% for geometry, 97.2% for comprehensive mathematics outcomes, 96.1% for initial age, 98.2% for prediction intervals, 100% for publication type, and 99.2% for student learning status. Any coding discrepancies were resolved through discussion or reference to original studies.

Missing Data

Not all studies provided sufficient information on the variables of interest for the present study. In case of insufficient information, authors were contacted to obtain the missing information. However, if missing data could not be retrieved, especially for data missing for moderator variables, the study was excluded from the moderator analysis for which data were missing but was included in all moderator analyses for which data were provided.

Data Analysis

To calculate the overall average effect size, we used Pearson's *r* correlation coefficient as the effect size for the meta-analysis. Because of the different characteristics of participants and measurements across studies, we chose a random-effects model to calculate the overall average effect size (Hedges et al., 2010) and ran weighted random-effects meta-regression models using Hedges et al.'s (2010) corrections with the "robumeta" package (Z. Fisher et al., 2017) in *R* version 4.0.0 (R Core Team, 2020).

To answer research question 1, we first transformed the Pearson's correlation coefficients to Fisher's *z* scores (Fisher, 1915). We calculated the overall weighted mean correlations and mean variance correlations of all Fisher's *z* between early numeracy and later mathematics. Then we estimated the weighted mean correlations by subtypes of early numeracy, types of later mathematics, publication type, and student learning status (Borenstein et al., 2005; see Tables 1 and 2).

Next, we built three types of meta-regression models with all moderators in the model to explore whether different early numeracy subtypes show differences in predicting different later mathematics: (1) We used the overall weighted mean correlations as the outcome to determine if the subtype of early numeracy was a significant moderator (Model 1, see Table 3); (2) We used the weighted mean correlations between early numeracy and *each* type of later mathematics as the outcome to determine if the subtype of early numeracy was a significant moderator (Model 2, see Tables 4–7); (3) We used the weighted mean correlations between *each* subtype of early numeracy and later mathematics as the outcome to determine if the type of later mathematics was a significant moderator (Model 3, see Tables 8–10).

To answer question 2, we used the overall weighted mean correlations as the outcome to assess whether the type of later mathematics, prediction interval, the square of the prediction interval, initial age, and student learning status are significant moderators (see Model 3).

Benjamini-Hochberg procedure was used to adjust the *p*-values for multiple comparisons within early numeracy and later mathematics (Benjamini et al., 2009). This method controls the false discovery rate by ranking the observed *p*-values from lowest to highest, then adjusting each *p*-value by multiplying it by the number of tests divided by its rank.

Publication Bias

We conducted Egger's regression test in *R* to examine publication bias, which incorporates robust variance estimation (i.e., standard errors predicting correlations between early numeracy and later mathematics). Funnel plots were also used for eyeballing possible outliers, as a basis of sensitivity analysis (Rodgers & Pustejovsky, 2021). The standard errors of correlations significantly predicted correlations between early numeracy and later mathematics, $\beta = -11.852$, $df = 576$, $p = .001$. We then examined the funnel plots and conducted sensitivity analyses. The funnel plots seemed relatively symmetrical (see Figure 3), and sensitivity analyses excluding possible outliers showed a similar pattern to that of analyses that included these apparent outliers. We therefore decided not to conduct any corrections for publication bias corrections to avoid introducing extra publication bias (Carter et al., 2019). All data were included in all the analyses.

Transparency and Openness

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study, and we follow journal article reporting standards (Kazak, 2018). All data, analysis code, and research materials are available at https://osf.io/yebjh/?view_only=a84fafdaceb140ffa25eb79f07880d91. Data were analyzed using R, version 4.0.0 (R Core Team, 2020) and the package robumeta, version 2.1 (Z. Fisher et al., 2017). This study's design and its analysis were not pre-registered.

Results

We included 54 studies with 137 independent samples (combinations of different measurement time points within a study) from 12 countries, both English-speaking (e.g., the U.S., Australia, Britain, and Canada) and non-English-speaking (Belgium, China, Finland, Germany, Netherlands, Norway, Sweden, and Turkey). Overall, 127 independent samples were from peer-reviewed articles and 10 from dissertations. There were 17 independent samples with mathematics learning disabilities and 120 with typically developing students. For different subtypes of early numeracy, 72 independent samples were assessed with numbering, 43 with relations, 43 with arithmetic operations, and 32 with comprehensive early numeracy. For later mathematics, 30 independent samples were assessed with early numeracy, 21 with fact fluency, 29 with word problems, 60 with calculations, 3 with algebra, 3 with geometry, and 79 with comprehensive mathematics. The mean initial age of measuring early numeracy was 5.92 years, *SD* = 0.64, age range = 3 to 7.1. The mean age of measuring later mathematics was 8.66 years, *SD* = 1.79, age range = 6.5 to 13.5. Table 1 shows the detailed descriptive information on the number of independent samples and effect sizes for each moderator.

Question 1: what are the longitudinal correlations between early numeracy measured at and/or before the first formal schooling year and mathematics measured six months apart or later?

Overall, early numeracy measured at and/or before the first formal schooling year was significantly related to mathematics at six months or later, *r* = .49, 95% CI [.47 .52]. As Table 1 shows, the average correlations between early numeracy and later mathematics achievement for each subtype of early numeracy were significant: numbering (212 correlations), *r* = .44, 95% CI [.40 .47]; relations (185 correlations), *r* = .39, 95% CI [.34 .43]; arithmetic operations (106 correlations), *r* = .49, 95% CI [.45 .53]; comprehensive skills (75 correlations), *r* = .63, 95% CI [.60 .66].

The average correlations between early numeracy and each type of later mathematics were significant: early numeracy (135 correlations), *r* = .43, 95% CI [.34 .50]; fact fluency (78 correlations), *r* = .40, 95% CI [.33 .47]; word problems (49 correlations), *r* = .61, 95% CI [.56 .65]; calculations (96 correlations), *r* = .49, 95% CI [.46, .51]; algebra (10 correlations), *r* = .48, 95% CI [.20 .69]; geometry (10 correlations), *r* = .41, 95% CI [.41, .58]; comprehensive skills (200 correlations), *r* = .54, 95% CI [.51 .57].

Question 2: Is the relation between early numeracy and later mathematics moderated by subtypes of early numeracy, types of later mathematics, initial age of early numeracy measurement, prediction intervals, and student learning status?

Types of Early Numeracy and Types of Later Mathematics

As Table 3 shows, after controlling for all other moderators, there were no differences among numbering, relations, and arithmetic operations in their relations to later mathematics. However, early numeracy (as a whole) was more strongly related to word problems than to early numeracy and calculations (early numeracy vs. word problems: $\beta = -.19$; word problems vs. calculations: $\beta = .12$).

As Tables 4 – 7 show, for relations between early numeracy and each type of later mathematics, after controlling for all other moderators, there were no differences among numbering, relations, and arithmetic operations in their relations to later mathematics. Due to the limited number of studies on algebra and geometry, we were unable to conduct moderation analysis on these later mathematics skills.

As Tables 8 – 10 show, for relations between each subtype of early numeracy and later mathematics, after controlling for all other moderators, numbering was more closely related to word problems than to early numeracy ($\beta = -.25$), and arithmetic operations were also more closely related to word problems than to other mathematics (early numeracy vs. word problems: $\beta = -.62$; fact fluency vs. word problems: $\beta = -.51$; word problems vs. calculations: $\beta = .52$). Relations did not predict different later mathematics differently.

All these results taken together did not provide a clear and consistent pattern that different types of early numeracy predicted different types of later mathematics differently, which suggests early numeracy in general may be a unitary construct.

Prediction Intervals

As Table 3 shows, after controlling for all other moderators, the prediction interval and the square of the prediction intervals had significant effects on the relations between early numeracy and later mathematics. As Tables 8 and 9 show, after controlling for all other moderators, the prediction interval and the square of the prediction intervals were significant in the relations between numbering/relations and later mathematics, but not in the relations between arithmetic operations and later mathematics.

Based on the meta-regression models, we visualized the effects of prediction intervals on the relations between early numeracy and later mathematics. Specifically, we formulated an equation for the effects of prediction intervals on the relations between overall early numeracy and later mathematics:

$$y = 0.75 - 0.18x + 0.19x^2 + k_1 * x_1 + k_2 * x_2 + \ldots + k_n * x_n,$$

where y represented the Fisher's z score of the correlation between early numeracy and later mathematics, x was the prediction interval, and x_1 to x_n represented various other moderating moderators such as subtypes of early numeracy, domains of mathematics outcomes, age, and publication types. The corresponding beta values for these moderators were denoted by k_1 to k_n. The positive coefficient of x^2 indicated that the relations between overall early numeracy and later mathematics strengthen with longer prediction intervals.

Likewise, we plotted the relations between numbering/relations/arithmetic operations and later mathematics (see Figure 4). Specifically, the equations for these relationships are as follows: For numbering, $y = 0.705 - 0.225x + 0.234x^2 + k_1x_1 + k_2x_2 + \ldots + k_nx_n$; for relations, $y = 0.362 + 0.395x + 0.440x^2 + k_1x_1 + k_2x_2 + \ldots + k_nx_n$; and for arithmetic operations, $y = 0.474 – 0.030x + 0.059x^2 + k_1x_1 + k_2x_2 + \ldots + k_n*x_n$. Notably, for arithmetic operations, the coefficients for both the prediction interval (x) and the square of the prediction interval (x^2) were not statistically significant.

Other Moderators

As Tables 5 and 8 show, after controlling for all other moderators, the relation between numbering and later mathematics and between early numeracy (as a whole) and fact fluency was stronger among students with mathematics learning disabilities than among typically developing students. As Table 6 shows, after controlling for all other moderators, the relation between early numeracy and later word problems was stronger among typically developing students than among students with mathematics learning disabilities.

Discussion

In the present longitudinal meta-analysis, early numeracy measured at and/or before the first year of formal schooling was moderately related to later mathematics measured six months apart or later. Three types of early numeracy showed a similar relation with later mathematics. After controlling for all other moderators, the prediction interval and the square of the prediction intervals moderated the relations between early numeracy and later mathematics, suggesting that early numeracy's prediction of later mathematics grew stronger over time. The earlier early numeracy was assessed, the stronger early numeracy's prediction of later mathematics performance. Early numeracy was more predictive of later advanced mathematics skills such as word problems than of foundational mathematics skills such as fact fluency and calculations. In the following, we discuss these findings in detail.

Unitary vs. Diverse Nature of Early Numeracy

Based on a series of moderation models, we did not find a clear and consistent pattern that different types of early numeracy predicted different types of later mathematics differently, which suggests early numeracy in general may be a unitary construct. This conclusion is in line with the empirical studies that supported the one-factor model of early numeracy (Clements et al. 2008; Dierendonck et al., 2021; Thomas et al. 2023). Our findings also help explain the high correlations (r = .80 ~ .88) among the three early numeracy subtypes in studies that reported early numeracy as a three-factor construct (Aunio et al., 2006; Jordan et al., 2006; Purpura & Lonigan, 2013).

Dierendonck et al. (2021) suggested a considerable portion of the variance was shared across all items of early numeracy measures, implying a general factor underlying early numeracy, which could be a domain-general ability (common cognitive abilities), a domain-specific ability (numeral knowledge), or a mix of both. For example, some research suggested all three early numeracy subtypes significantly correlated with verbal working memory (Purpura et al., 2017). Yet, numbering seemed to show stronger relations with inhibition and flexibility (Purpura et al., 2017), and arithmetic operations seemed to tap more reasoning and working memory in general (Dierendonck et al., 2021). Future studies adopting the meta-analytic structural equation modeling, including important cognitive factors such as working memory and reasoning, may help better explore whether and to what extent common cognitive abilities contribute to the unitary nature of early numeracy.

Predictive Nature of Early Numeracy: Steppingstone vs. Snowballing

Another aim of this study is to investigate how early numeracy influences mathematics development. Based on the steppingstone hypothesis, early numeracy is important only in predicting foundational mathematics, and its prediction of later mathematics decreases with prediction intervals and with an earlier initial early numeracy assessment time. Based on the snowballing trigger hypothesis, early numeracy should be important in predicting advanced mathematics, and its prediction of later mathematics increases with prediction intervals and with an earlier initial early numeracy assessment. Compared to snowballing hypothesis, the steppingstone hypothesis appears to garner stronger support, primarily due to a statistical artifact wherein measurements taken in closer proximity exhibit higher correlations compared to those taken further apart.

Our findings in general supported the snowballing trigger hypothesis. On the one hand, we found that the relations between early numeracy and later mathematics increased quadratically with prediction intervals. This pattern was rather robust across models in which we used different subtypes of early numeracy (i.e., numbering and relations) as predictors. Of note, arithmetic operations seemed to have a snowballing effect on later mathematics (see Figure 4). However, the coefficients for the prediction interval and its square of the prediction interval were not significant. This may be due to the shorter time span of the intervals examined (5.5 years) compared to those for numbering (6 years) and relations (6.16 years). Further research is needed to explore whether arithmetic operations truly have a long-term snowballing effect on mathematics performance. On the other hand, early numeracy (as a whole) was more predictive of later advanced mathematics (word problems) than of later fundamental mathematics (early numeracy and calculations). For each subtype of early numeracy, in comparison with fundamental mathematics such as early numeracy, fact fluency, and calculations, advanced mathematics (word problems) seemed to be more closely related to numbering and arithmetic operations.

One plausible explanation for such a snowballing effect is the accumulative nature of mathematics development. That is, an earlier and better mastery of early numeracy facilitates a better development of sequentially close or similar calculation skills, which leads to better acquisition of advanced mathematics with grades (Aunola et al., 2004; Geary et al., 2012; Lee et al., 2016). Also, an earlier and better mastery of early numeracy before formal schooling, even without systematic learning of other mathematics skills, seems to lay a solid foundation for mathematics learning when formal schooling starts (Casey et al., 2018; Demetriou et al., 2017; Geary et al., 2018).

In addition, some early numeracy skills involve processes that can improve children's working memory and reasoning, which are important abilities for later advanced mathematics skills. For example, for relations tasks to compare items of different sizes in each group, children may count one group, memorize the last number counted, count the other group, and then compare the sizes. This process heavily engages and enables one to practice numerical working memory, which is often considered a core skill in mathematics development (Geary, 1993; Gersten et al., 2005; Peng et al., 2016; Swanson & Jerman, 2006). Further, for arithmetic operation tasks such as addition and subtraction questions presented in the form of tables, charts, and graphs, children need to exercise reasoning skills to interpret and process numerical information (Dierendonck et al., 2021).

Mutualism in education may be another explanation for the snowballing effect of early numeracy. Given the theory of mutualism in education (Peng & Kievit, 2020), the progressive development of academic tasks (e.g., mathematics) involves heavy use of both cognition (e.g., executive function; Clark et al., 2013; Fung et al., 2020; Kyttälä et al., 2019; Ostergren & Traff, 2013; Ribner et al., 2020; Zhang et al., 2022) and social emotional skills (e.g., attitude, motivation, self-efficacy, anxiety; Ashcraft & Krause, 2007; Barroso et al., 2020). Mathematics, cognition, and social emotional skills may reciprocally contribute to each other's growth, leading to a synergistic cycle of development (e.g., Zhang & Peng, 2023). A better mastery of early numeracy early on is more likely to improve mathematics development, which may trigger mutualism among mathematics, cognition, and social emotional development.

Other Moderators

We did not find many other significant moderators. However, we found the relation between numbering and later mathematics and between early numeracy (as a whole) and fact fluency was stronger among students with mathematics learning disabilities than among typically developing students. That said, we found that the relation between early numeracy (as a whole) and later word problems was weaker among students with mathematics learning disabilities than among typically developing students. These results in general are in line with previous studies, suggesting more heterogeneity in early numeracy among students with mathematics learning disabilities, which may lead to a stronger relation between early numeracy and later mathematics, especially fundamental mathematics (Aunio, 2019; Aunio & Niemivirta, 2010; Desoete et al., 2009; Devlin et al., 2022; Jordan et al., 2006).

Limitations

Our findings should be interpreted with some limitations. First, we detected publication bias. We did not reach out to any listservs to seek additional grey literature beyond what is found in the dissertation database, which could be a potential limitation related to publication bias. That said, we controlled for publication type in all moderation analyses. We also ran sensitivity analyses excluding outliers, which did not produce different result patterns. In addition, in comparison with meta-analysis studies of interventions, meta-analysis of correlations is less likely to be influenced by publication bias (e.g., Chow & Ekholm, 2018; Lipsey & Wilson, 2001). Thus, publication bias may not have exerted a large impact on our findings. Second, statistical power was limited for some moderators such as types of later mathematics (e.g., algebra, geometry) and student learning status, especially in the moderation analyses for each early numeracy subtype and each type of later mathematics. Thus, the moderation results from these analyses should be interpreted with caution. Third, given data limitations, we were unable to investigate a multiple-mediator model (e.g., early numeracy→fact fluency→calculations→word problems), which might provide more direct evidence for or against the steppingstone and snowballing trigger hypotheses for early numeracy. Thus, our evidence for the snowballing effect of early numeracy should be considered inferential in nature.

Implications

With all limitations in mind, this is the first longitudinal meta-analysis to systematically investigate the relations between early numeracy and later mathematics. Theoretically, our findings support the unitary construct of early numeracy and the sequential and accumulative nature of mathematics development. Early numeracy is important for foundational mathematics but also a trigger for snowballing effects of mathematics development in general. As a trigger, early numeracy may not only manifest in knowledge accumulation within the mathematics domain, but also be magnified by mutualism among mathematics and mathematics-relevant skills such as cognition and social-emotional skills with development in general (Peng & Kievit, 2020; Zhang & Peng, 2023).

From a practical perspective, our findings may have implications for early numeracy assessment and instruction. Assessing a comprehensive set of early numeracy skills is more likely to reflect early mathematics performance and to be used for the identification of students at risk for mathematics learning disabilities. The snowballing effects of early numeracy suggest that early numeracy should be a component in early mathematics instruction regardless of students' ages (at and/or before formal schooling) and learning status. This is in line with recent research on the importance of early numeracy interventions (Charitaki et al., 2021; Nelson & McMaster, 2019) and the significance of the early mathematics home environment (Daucourt et al., 2021) for young students with and without mathematics learning disabilities. Early numeracy interventions for students with mathematics learning disabilities are important for reducing the widening achievement gap between them and their typically developing peers with development (Davis-Kean et al., 2022; Morgan et al., 2009). All said, these implications are based on correlational data. We hope the present study can offer a theoretical anchor for future experimental studies to test the mechanisms that underlie the relation between early numeracy and mathematics development.

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Figure 1

The Hypothesis of Predictive Nature of Early Numeracy

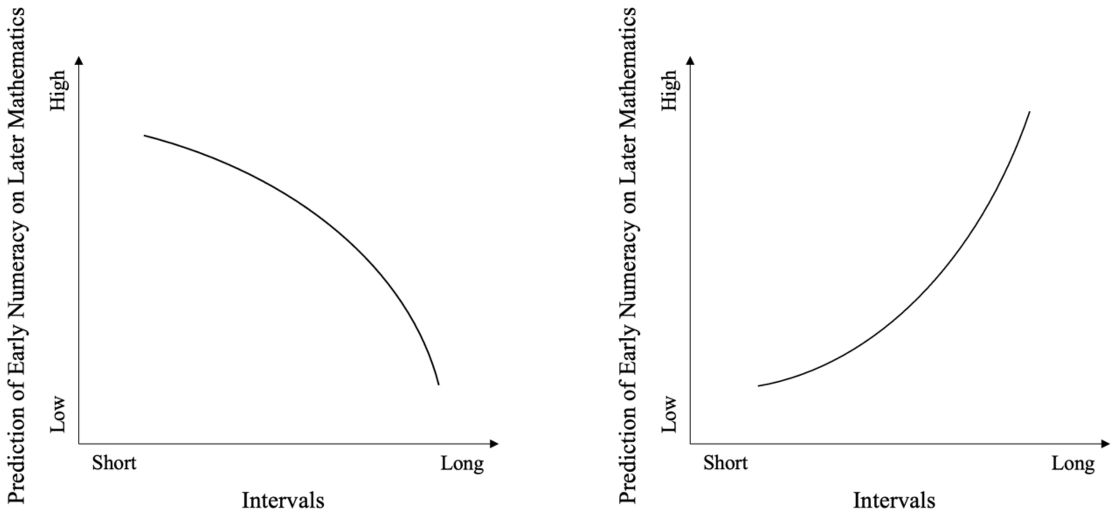


Figure 1a Stepping-stone Hypothesis Figure 1b Snowballing Effects

Note. We employed the equation $y = a + bx + cx^2$ to depict the influence of prediction intervals on the relationship between early numeracy and subsequent mathematics achievements, where y = the correlation between early numeracy skills and later mathematics, and x = the prediction interval. The direction of the trend line (ascending or descending) is determined by whether the value of c is positive or negative. In Figure 1a, the value of c should be negative, indicating a downward trend; in Figure 1b, it should be positive, suggesting an upward trend.

Figure 2

Literature Search and Selection Process

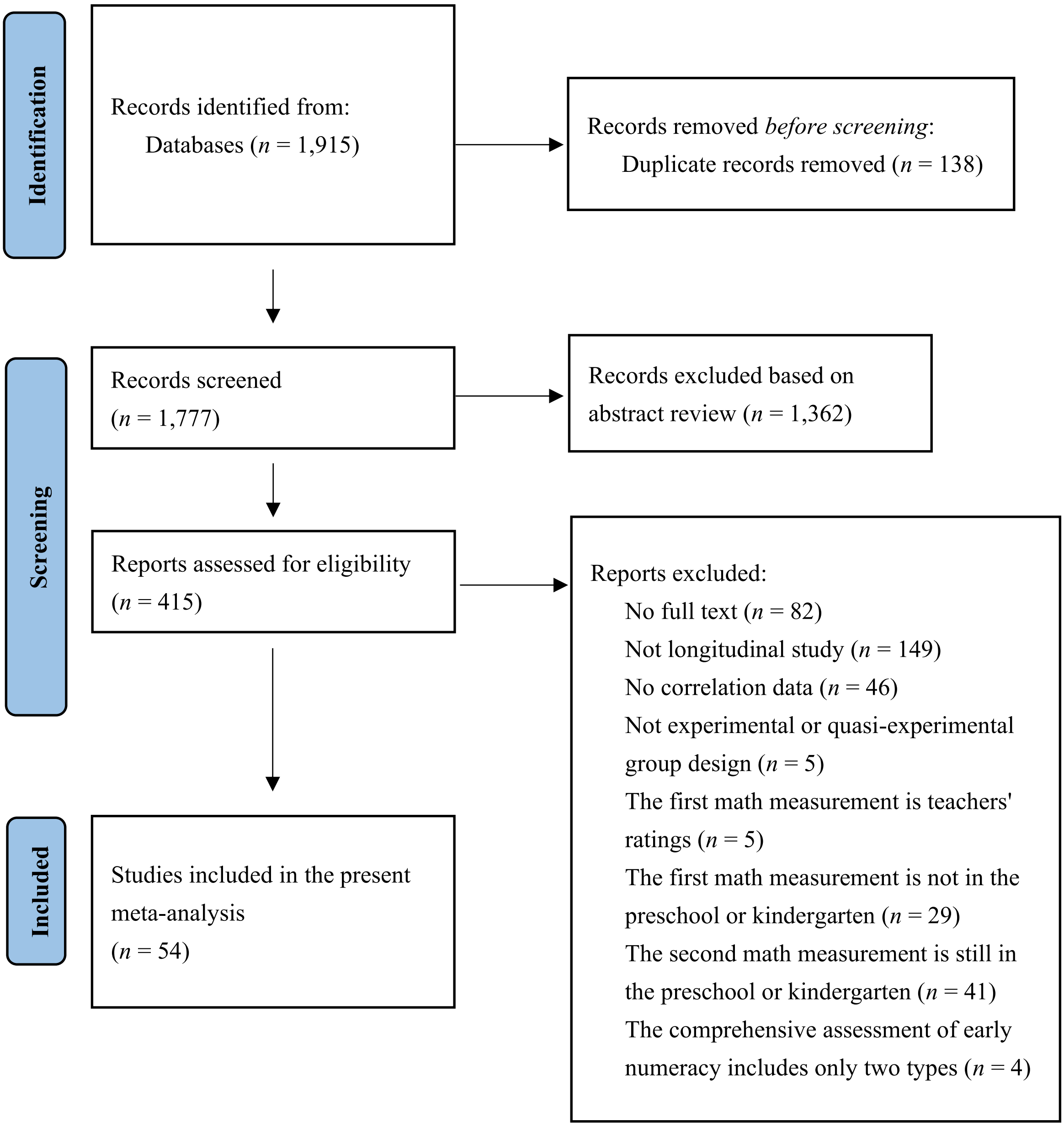


Figure 3
Funnel Plot

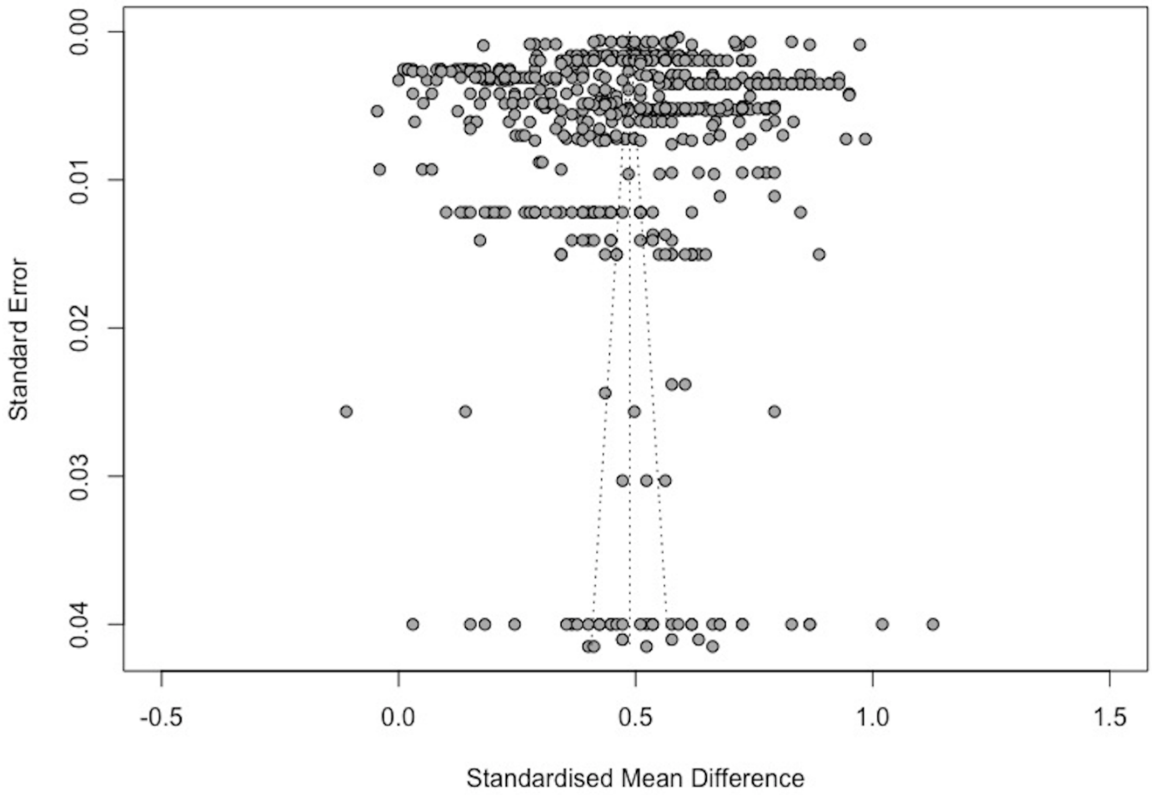
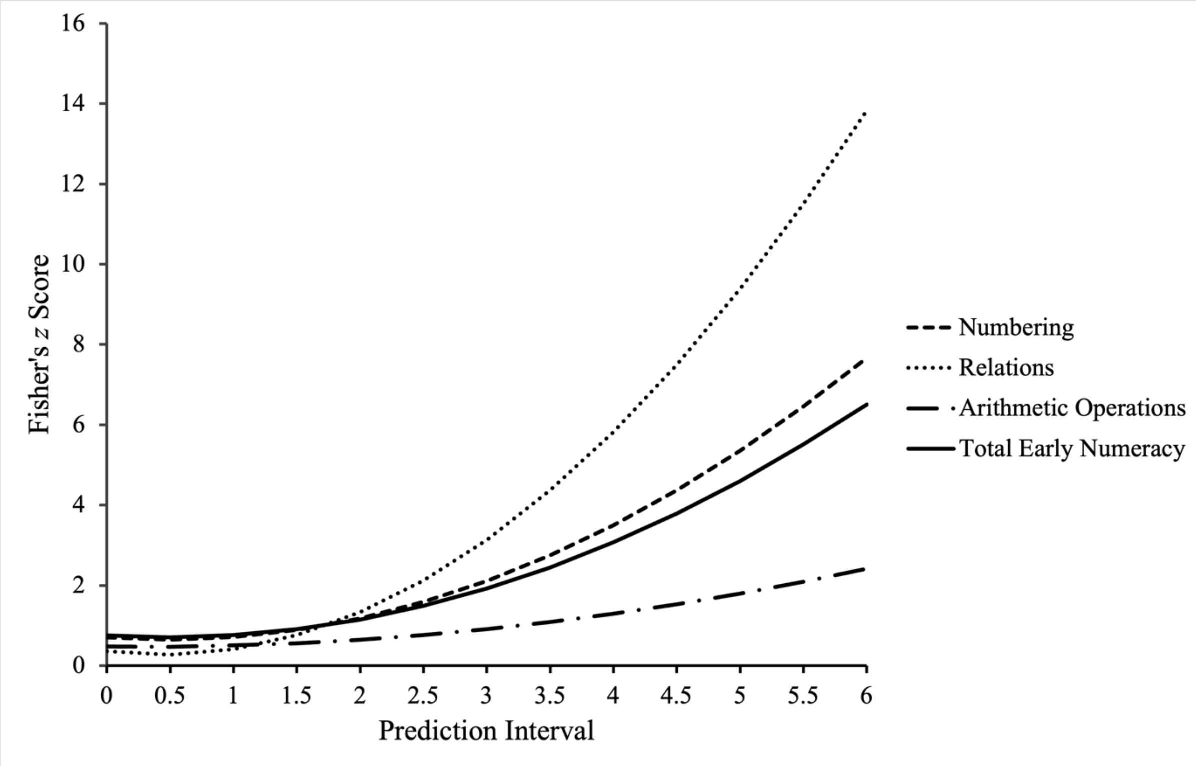


Figure 4

Predictive Nature of Each Subtype of Early Numeracy



Note. Based on Table 3 and Tables 8–10, after controlling for publication type, student learning status, and the initial age of measuring early numeracy, and standardizing age and prediction intervals, we plotted four lines to present the impact of prediction intervals on the relations between total early numeracy (as well as each subtype of early numeracy) and later mathematics: Total early numeracy: $y = 0.750 - 0.181x + 0.187x^2$; Numbering: $y = 0.705 - 0.225x + 0.234x^2$; Relations: $y = 0.362 + 0.395x + 0.440x^2$; Arithmetic operations: $y = 0.474 – 0.030x + 0.059x^2$. y is the Fisher's z score of the relation between early numeracy and later different mathematics outcomes, and x is the prediction interval. However, for arithmetic operations, the coefficients for both the prediction interval (x) and the square of the prediction interval (x^2) were not statistically significant.

Table 1

The Predictive Effect of Early Numeracy on Later Mathematics Achievement

Measure	Number of effect sizes	Correlation	*df*	Correlation 95% CI	Between-study sampling variance (τ^2)
Main average correlation	578	.494**	133.00	[.468, .518]	.033
Publication Type					
1. Peer-reviewed	511	.493**	125.00	[.466, .519]	.033
2. Non-peer-reviewed	67	.506**	6.97	[.450, .559]	.015
Student Type					
1. Mathematics Learning Disabilities	71	.459**	15.90	[.372, .538]	.056
2. Typical Developing Students	507	.498**	116.00	[.472, .525]	.032
Domains of Early Numeracy					
1. Numbering	212	.435**	66.50	[.403, .465]	.018
2. Relations	185	.386**	39.90	[.340, .431]	.029
3. Arithmetic Operations	106	.491**	41.60	[.452, .528]	.025
4. Comprehensive Early Numeracy	75	.631**	30.90	[.604, .656]	.018
Domains of Mathematics Outcomes					
1. Early Numeracy	135	.427**	28.80	[.343, .504]	.068
2. Fact Fluency	78	.400**	19.80	[.328, .467]	.042
3. Word Problems	49	.608**	27.90	[.559, .653]	.035
4. Calculations	96	.485**	58.40	[.456, .512]	.017
5. Algebra	10	.480*	2.00	[.203, .686]	.015
6. Geometry	10	.408*	2.00	[.206, .576]	.007

7. Comprehensive Mathematics	200	.541**	76.10	[.509, .571]	.040

Note. 95% CI = lower bound and upper bound of the confidence interval; τ^2 = between-study sampling variance. * $p < .05$; ** $p < .01$.

Table 2

The Predictive Effect of Subtypes of Early Numeracy on Later Mathematics

	Number of correlations	Correlation	*df*	Correlation 95% CI	Between-study sampling variance (τ^2)
Numbering					
1. Early Numeracy	42	.336**	12.70	[.224, .441]	.039
2. Fact Fluency	32	.409**	12.80	[.310, .498]	.041
3. Word Problems	18	.496**	4.99	[.312, .645]	.046
4. Calculations	35	.422**	19.70	[.384, .458]	.006
5. Algebra	6	.484*	2.00	[.212, .687]	.015
6. Geometry	6	.403**	2.00	[.247, .538]	.003
7. Comprehensive Mathematics	73	.470**	35.50	[.430, .508]	.024
Relations					
1. Early Numeracy	65	.363**	11.80	[.242, .472]	.044
2. Fact Fluency	24	.341**	8.98	[.175, .488]	.063
3. Word Problems	9	.453*	4.00	[.178, .662]	.085
4. Calculations	18	.392**	11.00	[.272, .501]	.047
5. Algebra	3	.478*	2.00	[.164, .704]	.018
6. Geometry	3	.409*	2.00	[.151, .616]	.011
7. Comprehensive Mathematics	63	.414**	24.40	[.366, .459]	.020
Arithmetic Operations					
1. Early Numeracy	21	.410**	5.99	[.240, .556]	.035
2. Fact Fluency	21	.415**	9.88	[.337, .488]	.023

3. Word Problems	1				
4. Calculations	22	.503**	16.70	[.446, .556]	.017
5. Algebra	1				
6. Geometry	1				
7. Comprehensive Mathematics	39	.513**	18.90	[.464, .559]	.023
Comprehensive Early Numeracy					
1. Early Numeracy	7	.738**	5.99	[.536, .941]	.051
2. Fact Fluency	1				
3. Word Problems	21	.794**	19.70	[.764, .824]	.001
4. Calculations	21	.626**	19.60	[.605, .647]	0
5. Algebra	0				
6. Geometry	0				
7. Comprehensive Mathematics	25	.794**	23.90	[.752, .837]	.011

Note. In the results for arithmetic operations and later mathematics, the numbers of correlations for calculations, algebra, and geometry were less than two, preventing the calculation of correlations. 95% CI = lower bound and upper bound of the confidence interval; τ^2 = between-study sampling variance. * $p < .05$; ** $p < .01$.

Table 3

Moderation Analysis of the Predictive Effect of Early Numeracy on Later Mathematics

Measure	Beta	*SE*	*t*	*df*	95% CI	*p* value
Domains of Early Numeracy						
1. Numbering vs. Relations	.054	.031	1.763	37.93	[-.008, .116]	.108
2. Numbering vs. Arithmetic Operations	-.025	.036	-.704	43.75	[-.098, .047]	.485
3. Numbering vs. Comprehensive Early Numeracy	-.270	.030	-8.941	50.51	[-.331, -.209]	< .001
4. Relations vs. Arithmetic Operations	-.079	.043	-1.861	32.40	[-.166, .007]	.108
5. Relations vs. Comprehensive Early Numeracy	-.324	.043	-7.516	53.12	[-.410, -.237]	< .001
6. Arithmetic Operations vs. Comprehensive Early Numeracy	-.245	.040	-6.070	58.67	[-.325, -.164]	< .001
Domains of Mathematics Outcomes						
1. Early Numeracy vs. Fact Fluency	-.074	.058	1.292	21.98	[-.194, .045]	.339
2. Early Numeracy vs. Word Problems	**-.188**	**.051**	**-3.647**	**18.48**	**[-.295, -.080]**	**.021**
3. Early Numeracy vs. Calculations	-.064	.043	-1.514	44.21	[-.150, .021]	.268
4. Early Numeracy vs. Algebra	-.220	.071	-3.117	2.87	[-.450, .011]	.160
5. Early Numeracy vs. Geometry	-.126	.056	-2.237	2.87	[-.310, .058]	.268
6. Early Numeracy vs. Comprehensive Mathematics	-.153	.035	-4.408	37.17	[-.223, -.082]	< .001
7. Fact Fluency vs. Word Problems	-.113	.066	-1.721	18.14	[-.252, .025]	.196
8. Fact Fluency vs. Calculations	.010	.050	.199	28.05	[-.092, .112]	.843
9. Fact Fluency vs. Algebra	-.145	.080	-1.820	3.08	[-.396, .105]	.287
10. Fact Fluency vs. Geometry	-.052	.067	-.771	3.08	[-.263, .159]	.579
11. Fact Fluency vs. Comprehensive Mathematics	-.078	.053	-1.469	30.34	[-.187, .031]	.268
12. Word Problems vs. Calculations	**.123**	**.034**	**3.590**	**20.65**	**[.052, .195]**	**.021**
13. Word Problems vs. Algebra	-.032	.070	-.455	3.42	[-.241, .177]	.711
14. Word Problems vs. Geometry	.062	.057	1.081	3.42	[-.108, .231]	.49
15. Word Problems vs. Comprehensive Mathematics	.035	.039	.897	20.57	[-.046, .117]	.499

16. Calculations vs. Algebra	-.155	.064	-2.432	2.48	[-.384, .074]	.268
17. Calculations vs. Geometry	-.062	.050	-1.246	2.48	[-.240, .116]	.476
18. Calculations vs. Comprehensive Mathematics	-.088	.027	-3.237	55.05	[-.143, -.034]	.021
19. Algebra vs. Geometry	.094	.024	3.913	1.96	[-.011, .198]	.196
20. Algebra vs. Comprehensive Mathematics	.067	.064	1.045	2.26	[-.181, .315]	.499
21. Geometry vs. Comprehensive Mathematics	-.026	.049	-.540	2.26	[-.215, .163]	.705
Age (T1)	-.036	.098	-.366	13.49	[-.246, .175]	.720
Interval	**-.181**	**.073**	**-2.491**	**49.23**	**[-.327, -.035]**	**.016**
Interval^2	**.187**	**.073**	**2.583**	**41.03**	**[.041, .334]**	**.013**
Age (T1) * Interval	.271	.314	.863	17.68	[-.390, .931]	.400
Age (T1) * Interval^2	-.327	.477	-.685	15.72	[-1.339, .686]	.503
Age (T1) * Interval * Interval^2	.049	.098	.496	13.20	[-.162, .259]	.628
Publication Type (Peer-reviewed vs. Non-peer-reviewed)	**.126**	**.031**	**4.104**	**8.93**	**[.056, .195]**	**.003**
Student Type (Typically Developing Students vs. Mathematics Learning Disabilities)	.048	.075	.641	13.27	[-.113, .209]	.533

Note. All covariates and moderators were entered in one model. Several models were run for thorough subgroup comparisons among moderators with more than two categories. For the convenience of presentation, subgroup comparisons within categorical moderators are all listed in the model. The second group in each group comparison variable is the reference group (e.g., for numbering vs. relations, relations is the reference group in the dummy coding of early numeracy domains). There are 578 effect sizes and 137 independent samples. Between-study sampling variance (τ^2) is .0186. 95% CI = lower bound and upper bound of the confidence interval. Age (T1) represents the student's age at the time of early numeracy measurement. The data related to age and interval are standardized. We employed the Benjamini-Hochberg procedure to adjust the p-values for multiple comparisons of early numeracy and mathematics outcomes (Benjamini et al., 2009). We highlight significant results where the degrees of freedom (*df*) are larger than four and which are not related to comprehensive early numeracy or comprehensive mathematics outcomes.

Table 4

Moderation Analysis of the Predictive Effect of Early Numeracy on Later Early Numeracy

Measure	Beta	*SE*	*t*	*df*	95% CI	*p* value
Domains of Early Numeracy						
1. Numbering vs. Relations	-.030	.047	-.644	7.34	[-.141, .080]	.809
2. Numbering vs. Arithmetic Operations	-.018	.050	-.356	10.20	[-.130, .094]	.875
3. Numbering vs. Comprehensive Early Numeracy	-.417	.091	-4.611	8.41	[-.624, -.210]	.012
4. Relations vs. Arithmetic Operations	.012	.044	.284	6.86	[-.091, .116]	.875
5. Relations vs. Comprehensive Early Numeracy	-.387	.096	-4.014	7.27	[-.613, -.161]	.012
6. Arithmetic Operations vs. Comprehensive Early Numeracy	-.399	.094	-4.256	9.00	[-.612, -.187]	.012
Age (T1)	-.007	.287	-.026	8.14	[-.668, .653]	.980
Interval	**-.580**	**.212**	**-2.738**	**6.18**	**[-1.094, -.065]**	**.033**
Interval^2	.869	.268	3.237	3.59	[.089, 1.648]	.037
Age (T1) * Interval	-.129	.840	-.154	7.87	[-2.072, 1.814]	.882
Age (T1) * Interval^2	.335	1.334	.251	7.75	[-2.758, 3.428]	.808
Age (T1) * Interval * Interval^2	.023	.288	.079	7.19	[-.654, .700]	.939
Publication Type (Peer-reviewed vs. Non-peer-reviewed)	.158	.121	1.308	2.50	[-.275, .592]	.298
Student Type (Typically Developing Students vs. Mathematics Learning Disabilities)	.119	.052	2.297	4.62	[-.018, .256]	.074

Note. All covariates and moderators were entered in one model. Several models were run for thorough subgroup comparisons among moderators with more than two categories. For the convenience of presentation, subgroup comparisons within categorical moderators are all listed in the model. The second group in each group comparison variable is the reference group (e.g., for numbering vs. relations, relations is the reference group in the dummy coding of early numeracy domains). There are 135 effect sizes and 30 independent samples. Between-study sampling

variance (τ^2) is .01489. 95% CI = lower bound and upper bound of the confidence interval. Age (T1) represents the student's age at the time of early numeracy measurement. The data related to age and Interval are standardized. We employed the Benjamini-Hochberg procedure to adjust the p-values for multiple comparisons of early numeracy (Benjamini et al., 2009). We highlight significant results where the degrees of freedom (*df*) larger than four and which are not related to comprehensive early numeracy or comprehensive mathematics outcomes.

Table 5

Moderation Analysis of the Predictive Effect of Early Numeracy on Later Fact Fluency

Measure	Beta	*SE*	*t*	*df*	95% CI	*p* value
Domains of Early Numeracy						
1. Numbering vs. Relations	.104	.032	3.206	8.31	[.030, .177]	.072
2. Numbering vs. Arithmetic Operations	.066	.060	1.091	11.49	[-.066, .198]	.678
3. Numbering vs. Comprehensive Early Numeracy	.033	.054	.613	6.29	[-.098, .164]	.683
4. Relations vs. Arithmetic Operations	-.038	.048	-.779	9.47	[-.146, .071]	.683
5. Relations vs. Comprehensive Early Numeracy	-.070	.053	-1.338	6.43	[-.197, .056]	.678
6. Arithmetic Operations vs. Comprehensive Early Numeracy	-.033	.053	-.622	7.01	[-.158, .092]	.683
Age (T1)	**4.134**	**1.273**	**3.248**	**3.26**	**[.258, 8.010]**	**.042**
Interval	-.890	.369	-2.414	3.98	[-1.915, .136]	.074
Interval^2	.088	.725	.122	3.33	[-2.093, 2.270]	.910
Age (T1) * Interval	-9.064	2.878	-3.149	3.44	[-17.600, -.528]	.043
Age (T1) * Interval^2	16.167	4.948	3.268	3.34	[1.300, 31.034]	.040
Age (T1) * Interval * Interval^2	-4.166	1.306	-3.190	3.22	[-8.167, -.164]	.045
Publication Type (Peer-reviewed vs. Non-peer-reviewed)	**.292**	**.046**	**6.322**	**5.64**	**[.177, .406]**	**< .001**
Student Type (Typically Developing Students vs. Mathematics Learning Disabilities)	**-.212**	**.077**	**-2.771**	**6.58**	**[-.395, -.029]**	**.029**

Note. All covariates and moderators were entered in one model. Several models were run for thorough subgroup comparisons among moderators with more than two categories. For the convenience of presentation, subgroup comparisons within categorical moderators are all listed in the model. The second group in each group comparison variable is the reference group (e.g., for numbering vs. relations, relations is the reference group in the dummy coding of early numeracy domains). There are 78 effect sizes and 21 independent samples. Between-study sampling

variance (τ^2) is .01099. 95% CI = lower bound and upper bound of the confidence interval. Age (T1) represents the student's age at the time of early numeracy measurement. The data related to age and Interval are standardized. We employed the Benjamini-Hochberg procedure to adjust the p-values for multiple comparisons of early numeracy (Benjamini et al., 2009). We highlight significant results where the degrees of freedom (*df*) larger than four and which are not related to comprehensive early numeracy or comprehensive mathematics outcomes.

Table 6

Moderation Analysis of the Predictive Effect of Early Numeracy on Later Word Problems

Measure	Beta	*SE*	*t*	*df*	95% CI	*p* value
Domains of Early Numeracy						
1. Numbering vs. Relations	-.047	.026	-1.823	2.26	[-.147, .053]	.195
2. Numbering vs. Arithmetic Operations	-.388	.038	-10.333	1.88	[-.560, -.216]	.013
3. Numbering vs. Comprehensive Early Numeracy	-.244	.035	-6.878	6.39	[-.329, -.158]	< .001
4. Relations vs. Arithmetic Operations	-.341	.021	-16.161	2.08	[-.428, -.253]	.005
5. Relations vs. Comprehensive Early Numeracy	-.197	.024	-8.179	5.57	[-.257, -.137]	< .001
6. Arithmetic Operations vs. Comprehensive Early Numeracy	.144	.024	6.039	10.20	[.091, .197]	< .001
Age (T1)	-.129	.2331	-.554	7.76	[-.670, .412]	.595
Interval	-.174	.102	-1.705	8.00	[-.410, .062]	.127
Interval^2	.270	.158	1.707	6.05	[-.116, .656]	.138
Age (T1) * Interval	.687	.758	.920	8.00	[-1.036, 2.411]	.385
Age (T1) * Interval^2	-.916	1.117	-.820	8.16	[-3.482, 1.650]	.435
Age (T1) * Interval * Interval^2	.259	.292	.886	6.94	[-.433, .951]	.405
Student Type (Typically Developing Students vs. Mathematics Learning Disabilities)	**.393**	**.041**	**9.586**	**8.07**	**[.298, .487]**	**< .001**

Note. All covariates and moderators were entered in one model. Several models were run for thorough subgroup comparisons among moderators with more than two categories. For the convenience of presentation, subgroup comparisons within categorical moderators are all listed in the model. The second group in each group comparison variable is the reference group (e.g., for numbering vs. relations, relations is the reference group in the dummy coding of early numeracy domains). There are 49 effect sizes and 29 independent samples. Between-study sampling variance (τ^2) is .00817. 95% CI = lower bound and upper bound of the confidence interval. Age (T1) represents the student's age at the time of early numeracy measurement. The data related to age and Interval are standardized. We employed the Benjamini-Hochberg procedure to adjust the p-values for multiple comparisons of early numeracy (Benjamini et al., 2009). We highlight significant results where the degrees of freedom (*df*) larger than four and which are not related to comprehensive early numeracy or comprehensive mathematics outcomes.

Table 7

Moderation Analysis of the Predictive Effect of Early Numeracy on Later Calculations

Measure	Beta	*SE*	*t*	*df*	95% CI	*p* value
Domains of Early Numeracy						
1. Numbering vs. Relations	.068	.034	2.003	11.13	[-.007, .143]	.105
2. Numbering vs. Arithmetic Operations	.039	.058	.671	18.18	[-.083, .160]	.613
3. Numbering vs. Comprehensive Early Numeracy	-.278	.046	-6.006	23.38	[-.373, -.182]	< .001
4. Relations vs. Arithmetic Operations	-.029	.064	-.457	13.59	[-.167, .108]	.655
5. Relations vs. Comprehensive Early Numeracy	-.346	.066	-5.230	17.21	[-.485, -.206]	< .001
6. Arithmetic Operations vs. Comprehensive Early Numeracy	-.317	.072	-4.430	19.33	[-.466, -.167]	< .001
Age (T1)	.138	.145	.948	9.60	[-.188, .463]	.366
Interval	.053	.150	.353	20.09	[-.259, .365]	.728
Interval^2	.016	.135	.122	18.29	[-.266, .299]	.904
Age (T1) * Interval	-.118	.397	-.298	11.76	[-.985, .748]	.771
Age (T1) * Interval^2	.144	.622	.232	10.29	[-1.235, 1.524]	.821
Age (T1) * Interval * Interval^2	-.033	.141	-.237	8.02	[-.358, .291]	.819
Publication Type (Peer-reviewed vs. Non-peer-reviewed)	.298	.095	3.136	2.25	[-.070, .667]	.076
Student Type (Typically Developing Students vs. Mathematics Learning Disabilities)	.088	.084	1.050	1.76	[-.324, .501]	.416

Note. All covariates and moderators were entered in one model. Several models were run for thorough subgroup comparisons among moderators with more than two categories. For the convenience of presentation, subgroup comparisons within categorical moderators are all listed in the model. The second group in each group comparison variable is the reference group (e.g., for numbering vs. relations, relations is the reference group in the dummy coding of early numeracy domains). There are 96 effect sizes and 60 independent samples. Between-study sampling

variance (τ^2) is .01173. 95% CI = lower bound and upper bound of the confidence interval. Age (T1) represents the student's age at the time of early numeracy measurement. The data related to age and Interval are standardized. We employed the Benjamini-Hochberg procedure to adjust the p-values for multiple comparisons of early numeracy (Benjamini et al., 2009). We highlight significant results where the degrees of freedom (*df*) larger than four and which are not related to comprehensive early numeracy or comprehensive mathematics outcomes.

Table 8

Moderation Analysis of the Predictive Effect of Numbering on Later Mathematics

Measure	Beta	*SE*	*t*	*df*	95% CI	*p* value
Domains of Mathematics Outcomes						
1. Early Numeracy vs. Fact Fluency	-.066	.068	-.972	17.07	[-.208, .077]	.401
2. Early Numeracy vs. Word Problems	**-.247**	**.057**	**-4.345**	**6.47**	**[-.384, -.110]**	**.042**
3. Early Numeracy vs. Calculations	-.139	.052	-2.696	22.98	[-.246, -.032]	.091
4. Early Numeracy vs. Algebra	-.261	.079	-3.293	3.64	[-.490, -.032]	.184
5. Early Numeracy vs. Geometry	-.160	.058	-2.749	3.64	[-.327, .008]	.231
6. Early Numeracy vs. Comprehensive Mathematics	-.183	.048	-3.844	22.54	[-.281, -.084]	.179
7. Fact Fluency vs. Word Problems	-.182	.076	-2.408	5.67	[-.369, .006]	.231
8. Fact Fluency vs. Calculations	-.073	.046	-1.608	13.39	[-.172, .025]	.250
9. Fact Fluency vs. Algebra	-.195	.092	-2.114	3.80	[-.457, .066]	.240
10. Fact Fluency vs. Geometry	-.094	.071	-1.317	3.80	[-.296, .108]	.365
11. Fact Fluency vs. Comprehensive Mathematics	-.117	.064	-1.841	20.46	[-.250, .015]	.240
12. Word Problems vs. Calculations	.108	.052	2.071	5.84	[-.020, .237]	.240
13. Word Problems vs. Algebra	-.014	.080	-.171	4.56	[-.225, .198]	.872
14. Word Problems vs. Geometry	.088	.060	1.462	4.56	[-.071, .247]	.338
15. Word Problems vs. Comprehensive Mathematics	.065	.055	1.175	6.81	[-.066, .195]	.366
16. Calculations vs. Algebra	-.122	.065	-1.878	2.74	[-.340, .096]	.291
17. Calculations vs. Geometry	-.021	.040	-.520	2.74	[-.154, .113]	.674
18. Calculations vs. Comprehensive Mathematics	-.044	.037	-1.203	28.73	[-.119, .031]	.359
19. Algebra vs. Geometry	.101	.032	3.128	2.00	[-.038, .241]	.24
20. Algebra vs. Comprehensive Mathematics	.078	.061	1.288	2.39	[-.146, .302]	.380
21. Geometry vs. Comprehensive Mathematics	-.023	.034	-.689	2.39	[-.148, .102]	.610
Age (T1)	.055	.169	.328	8.83	[-.327, .438]	.751

Interval	**-.225**	**.098**	**-2.296**	**22.88**	**[-.429, -.022]**	**.031**
Interval^2	**.231**	**.094**	**2.449**	**20.61**	**[.035, .427]**	**.023**
Age (T1) * Interval	-.047	.544	-.086	10.20	[1.256, 1.163]	.933
Age (T1) * Interval^2	.176	.828	.213	9.57	[-1.679, 2.031]	.836
Age (T1) * Interval * Interval^2	-.055	.168	-.328	8.50	[-.437, .328]	.751
Publication Type (Peer-reviewed vs. Non-peer-reviewed)	**.179**	**.069**	**2.607**	**5.36**	**[.006, .352]**	**.045**
Student Type (Typically Developing Students vs. Mathematics Learning Disabilities)	**-.199**	**.067**	**-2.978**	**8.13**	**[-.352, -.045]**	**.017**

Note. All covariates and moderators were entered in one model. Several models were run for thorough subgroup comparisons among moderators with more than two categories. For the convenience of presentation, subgroup comparisons within categorical moderators are all listed in the model. The second group in each group comparison variable is the reference group (e.g., for numbering vs. relations, relations is the reference group in the dummy coding of early numeracy domains). There are 212 effect sizes and 72 independent samples. Between-study sampling variance (τ^2) is .01567. 95% CI = lower bound and upper bound of the confidence interval. Age (T1) represents the student's age at the time of early numeracy measurement. The data related to age and Interval are standardized. We employed the Benjamini-Hochberg procedure to adjust the p-values for multiple comparisons of mathematics outcomes (Benjamini et al., 2009). We highlight significant results where the degrees of freedom (*df*) larger than four and which are not related to comprehensive early numeracy or comprehensive mathematics outcomes.

Table 9

Moderation Analysis of the Predictive Effect of Relations on Later Mathematics

Measure	Beta	*SE*	*t*	*df*	95% CI	*p* value
Domains of Mathematics Outcomes						
1. Early Numeracy vs. Fact Fluency	-.090	.073	-1.235	8.91	[-.256, .076]	.893
2. Early Numeracy vs. Word Problems	-.161	.102	-1.581	4.40	[-.434, .112]	.893
3. Early Numeracy vs. Calculations	-.034	.054	-.631	12.76	[-.152, .083]	.893
4. Early Numeracy vs. Algebra	-.207	.090	-2.305	2.69	[-.511, .098]	.893
5. Early Numeracy vs. Geometry	-.121	.090	-1.343	2.69	[-.427, .186]	.893
6. Early Numeracy vs. Comprehensive Mathematics	-.113	.039	-2.877	9.10	[-.201, -.024]	.780
7. Fact Fluency vs. Word Problems	-.071	.119	-.593	4.99	[-.376, .235]	.893
8. Fact Fluency vs. Calculations	.056	.073	.774	10.95	[-.104, .216]	.893
9. Fact Fluency vs. Algebra	-.116	.110	-1.060	3.10	[-.459, .227]	.893
10. Fact Fluency vs. Geometry	-.031	.110	-.277	3.10	[-.375, .314]	.896
11. Fact Fluency vs. Comprehensive Mathematics	-.022	.086	-.261	15.37	[-.204, .160]	.896
12. Word Problems vs. Calculations	.127	.082	1.548	5.06	[-.083, .336]	.893
13. Word Problems vs. Algebra	-.046	.121	-.378	3.83	[-.386, .295]	.896
14. Word Problems vs. Geometry	.040	.121	.330	3.83	[-.303, .383]	.896
15. Word Problems vs. Comprehensive Mathematics	.048	.104	.462	5.29	[-.216, .312]	.893
16. Calculations vs. Algebra	-.172	.084	-2.053	2.53	[-.469, .125]	.893
17. Calculations vs. Geometry	-.086	.085	-1.016	2.53	[-.389, .215]	.893
18. Calculations vs. Comprehensive Mathematics	-.078	.057	-1.383	13.29	[-.201, .044]	.893
19. Algebra vs. Geometry	.086	.027	3.215	2.00	[-.029, .200]	.893
20. Algebra vs. Comprehensive Mathematics	.094	.091	1.027	2.18	[-.270, .458]	.893
21. Geometry vs. Comprehensive Mathematics	.008	.091	.090	2.18	[-.356, .372]	.936
Age (T1)	-.101	.231	-.437	3.11	[-.821, .619]	.691

Interval	**-.395**	**.155**	**-2.545**	**17.67**	**[-.722, -.069]**	**.021**
Interval^2	**.440**	**.176**	**2.493**	**14.14**	**[.062, .818]**	**.026**
Age (T1) * Interval	.326	.690	.472	4.96	[-1.451, 2.103]	.657
Age (T1) * Interval^2	-.421	1.072	-.392	4.19	[-3.345, 2.504]	.714
Age (T1) * Interval * Interval^2	.090	.227	.397	3.12	[-.617, .797]	.717
Publication Type (Peer-reviewed vs. Non-peer-reviewed)	.097	.060	1.637	10.02	[-.035, .230]	.133
Student Type (Typically Developing Students vs. Mathematics Learning Disabilities)	.109	.101	1.075	6.64	[-.133, .351]	.320

Note. All covariates and moderators were entered in one model. Several models were run for thorough subgroup comparisons among moderators with more than two categories. For the convenience of presentation, subgroup comparisons within categorical moderators are all listed in the model. The second group in each group comparison variable is the reference group (e.g., for numbering vs. relations, relations is the reference group in the dummy coding of early numeracy domains). There are 185 effect sizes and 43 independent samples. Between-study sampling variance (τ^2) is .02343. 95% CI = lower bound and upper bound of the confidence interval. Age (T1) represents the student's age at the time of early numeracy measurement. The data related to age and Interval are standardized. We employed the Benjamini-Hochberg procedure to adjust the p-values for multiple comparisons of mathematics outcomes (Benjamini et al., 2009). We highlight significant results where the degrees of freedom (*df*) larger than four and which are not related to comprehensive early numeracy or comprehensive mathematics outcomes.

Table 10

Moderation Analysis of the Predictive Effect of Arithmetic Operations on Later Mathematics

Measure	Beta	*SE*	*t*	*df*	95% CI	*p* value
Domains of Mathematics Outcomes						
1. Early Numeracy vs. Fact Fluency	-.103	.090	-1.138	10.32	[-.302, .097]	.468
2. Early Numeracy vs. Word Problems	**-.616**	**.084**	**-7.344**	**14.68**	**[-.795, -.437]**	**.001**
3. Early Numeracy vs. Calculations	-.095	.087	-1.091	15.25	[-.281, .091]	.468
4. Early Numeracy vs. Algebra	-.234	.120	-1.944	3.20	[-.603, .136]	.282
5. Early Numeracy vs. Geometry	-.199	.120	-1.653	3.20	[-.568, .171]	.347
6. Early Numeracy vs. Comprehensive Mathematics	-.223	.077	-2.890	13.27	[-.390, -.057]	.048
7. Fact Fluency vs. Word Problems	**-.513**	**.052**	**-9.796**	**9.99**	**[-.630, -.397]**	**.001**
8. Fact Fluency vs. Calculations	.007	.056	.129	12.42	[-.115, .129]	.946
9. Fact Fluency vs. Algebra	-.131	.106	-1.241	2.40	[-.521, .259]	.468
10. Fact Fluency vs. Geometry	-.096	.106	-.909	2.40	[-.486, .294]	.556
11. Fact Fluency vs. Comprehensive Mathematics	-.121	.059	-2.042	17.08	[-.246, .004]	.150
12. Word Problems vs. Calculations	**.520**	**.041**	**12.825**	**15.52**	**[.434, .607]**	**< .001**
13. Word Problems vs. Algebra	.382	.105	3.635	2.31	[-.017, .781]	.150
14. Word Problems vs. Geometry	.417	.105	3.969	2.31	[.018, .816]	.150
15. Word Problems vs. Comprehensive Mathematics	.392	.049	8.074	16.89	[.290, .495]	< .001
16. Calculations vs. Algebra	-.139	.118	-1.177	2.04	[-.636, .359]	.477
17. Calculations vs. Geometry	-.104	.118	-.879	2.04	[-.601, .394]	.556
18. Calculations vs. Comprehensive Mathematics	-.128	.058	-2.202	13.64	[-.253, -.003]	.150
19. Algebra vs. Geometry	.070	-	-	7.97	-	-
20. Algebra vs. Comprehensive Mathematics	.010	.096	.108	1.60	[.521, .542]	.946
21. Geometry vs. Comprehensive Mathematics	-.060	.096	-.619	1.60	[-.591, .471]	.680
Age (T1)	.012	.165	.071	6.49	[-.385, .409]	.945

Interval	-.030	.239	-.126	9.35	[-.568, .508]	.903
Interval^2	.059	.305	.195	9.49	[-.625, .744]	.850
Age (T1) * Interval	.231	.460	.503	8.05	[-.829, 1.292]	.629
Age (T1) * Interval^2	-.296	.719	-.412	7.09	[-1.991, 1.399]	.693
Age (T1) * Interval * Interval^2	.033	.160	.209	6.61	[-.350, .417]	.841
Publication Type (Peer-reviewed vs. Non-peer-reviewed)	.154	.054	2.854	3.70	[-.001, .309]	.051
Student Type (Typically Developing Students vs. Mathematics Learning Disabilities)	.103	.119	.868	10.34	[-.160, .367]	.405

Note. All covariates and moderators were entered in one model. Several models were run for thorough subgroup comparisons among moderators with more than two categories. For the convenience of presentation, subgroup comparisons within categorical moderators are all listed in the model. The second group in each group comparison variable is the reference group (e.g., for numbering vs. relations, relations is the reference group in the dummy coding of early numeracy domains). There are 106 effect sizes and 43 independent samples. Between-study sampling variance (τ^2) is .01665. 95% CI = lower bound and upper bound of the confidence interval. Age (T1) represents the student's age at the time of early numeracy measurement. The data related to age and Interval are standardized. We employed the Benjamini-Hochberg procedure to adjust the p-values for multiple comparisons of mathematics outcomes (Benjamini et al., 2009). We highlight significant results where the degrees of freedom (*df*) larger than four and which are not related to comprehensive early numeracy or comprehensive mathematics outcomes.