

*Original article*

# The Relationship between Home Math Environment and Early Mathematical Ability: A Meta-Analysis

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**Abstract:** The home math environment (HME) is a crucial factor influencing mathematical learning, yet the extent of its impact on early mathematical ability (MA) remains unclear. To further clarify the strength of this influence, this study employed meta-analysis to synthesize 82 relevant domestic and international research articles. Results revealed a moderate correlation between the HME and early MA, with significant differences observed in the effects of different sub-dimensions on early MA. Among these, parental math beliefs showed the strongest positive effect on MA, while parental math anxiety negatively predicted MA. Cultural background and research design moderated the relationship between HME and MA. To promote the development of young children's mathematical abilities, parents should cultivate accurate mathematical beliefs and increase the frequency and diversity of home math activities. Society and educational institutions should collaborate to effectively alleviate parental math anxiety through home education guidance, thereby enhancing children's mathematical capabilities.

**Keywords:** Home math environment; Early mathematical ability; Preschoolers; Meta-analysis

## 1. Introduction

As improving preschool education quality becomes a key priority in national education development, early cognitive skills of young children—particularly the development of mathematical ability—has garnered increasing attention. Research indicates that early mathematical abilities significantly predict later mathematical learning (Jordan et al., 2007), reading proficiency (Hidayatulloh et al., 2020), and problem-solving skills (Seitz & Weinert, 2022), and are closely linked to individual educational success, career achievement, and even a nation's economic growth (Onoshakpokaiye, 2023). However, although all young children have innate potential for mathematical learning, substantial individual differences in informal mathematical knowledge and experience emerge as early as ages 3–4 (Zhou et al., 2006). These disparities widen with age and cannot be fully bridged by school education alone (Zhou et al., 2006). Given the cumulative effects of early mathematical ability development (Morgan, Farkas, & Wu, 2011), exploring the key factors influencing preschoolers' mathematical development holds significant theoretical and practical value.

Sociocultural theory posits that individual cognition and behavior are constructed through social interaction and cultural environments (Hao et al., 2025). Early childhood mathematics learning is also influenced by two types of sociocultural factors. First, cultural expectations vary across societies. Different cultures exhibit significant variations on expectations regarding the value and importance of mathematics learning. Second, the home nurturing environment—a dynamic developmental process shaped by the combined influence of various subjective and objective factors within the family setting—exerts a critical impact on young children through caregivers' parenting beliefs and behaviors (Zhang & Liu, 2019). To be specific, when parents hold high expectations for their child's mathematical learning, they tend to engage in more frequent mathematical activities. Simultaneously, they influence the child's mathematical development through instruction, symbolic communication, and emphasizing certain behavioral traits. The HME encompasses math-related activities between parents and children at home, parental attitudes and expectations toward math, and the use of math language (LeFevre et al., 2009), serving as a crucial factor in early mathematical ability development. Ecological systems theory also emphasizes that family is a vital micro-system for children's learning and development. Previous research shows that Children's MA development is influenced by the quality and frequency of mathematical input (Bronfenbrenner, 1979). Through interactions with more experienced caregivers at home, young children gradually construct their own mathematical cognition (Vygotsky, 1978). Longitudinal studies further reveal that a favorable HME significantly predicts children's mathematical achievement in elementary school (Zhang, Liu, & Hu, 2019). Given the

importance of the HME for early childhood mathematics learning, great attention has been given to HME and its effect on young children's mathematical learning.

However, there is no consensus on the relationship between HME and preschoolers' mathematical abilities among previous research. Some studies indicate that home mathematical activities are significantly correlated with children's mathematical achievement (Skwarchuk et al., 2014; Ramani & Siegler, 2008). Other research suggests that specific types of home activities may negatively impact children if they exceed their zone of proximal development (Blevins-Knabe & Musun-Miller, 1996). One possible reason for this discrepancy lies in the differing definitions of home mathematical activities across existing studies. A review of the literature reveals that some studies focus on direct mathematical instruction, such as guiding children through arithmetic exercises (LeFevre et al., 2009; Skwarchuk et al., 2014). Other research examines indirect mathematical activities, such as the application of math in cooking or shopping (Ramani & Siegler, 2008; Vandermaas-Peeler et al., 2012). Whether children's mathematical ability development exhibits distinct characteristics based on the type of math activities they engage in at home remains unconfirmed by research. Furthermore, the extent to which parental factors—such as mathematical expectations, mathematical language input, and parental math anxiety—as integral components of the HME influence early mathematical ability development calls for further investigation.

Beyond the constituent elements of the HME, several variables may moderate the relationship between the two. First, the predictive power of the HME for early mathematical abilities is more pronounced in low-SES families than in high-SES families (Niklas & Schneider, 2014). Second, age may also serve as a crucial moderator. Research indicates that informal math activities correlate more strongly with math abilities in younger children, while formal math activities show stronger correlations with math abilities in older preschoolers (Skwarchuk et al., 2014). Third, parenting beliefs and behaviors differ across cultures. Parents holding an “effort-over-ability” belief perceive intensive home math activities as both necessary and effective. In contrast, parents with a “fixed ability” mindset tend to adopt a more laissez-faire approach, viewing early intervention as unnecessary (Cai & Hwang, 2002). Additionally, research design influences the relationship between home math activities and mathematical ability. Compared to cross-sectional studies, longitudinal research captures and analyzes the dynamic processes of variables over time, revealing stronger causal effects or developmental patterns (Dunst et al., 2016).

Meta-analysis is a method for synthesizing existing research findings, serving as an effective approach to address and evaluate conflicting research conclusions. Previous meta-analyses have examined the relationship between HME and math achievement as well as the association between home math activities and math skills (Daucourt et al., 2021; James et al., 2025). However, these studies primarily focused on school-age children within a single cultural context, lacking consideration for preschoolers and cultural differences. Given the distinct cognitive characteristics and learning styles of young children, HME may exhibit significant differences compared to other educational stages. Furthermore, mathematical learning among young children across cultural contexts exhibits distinct characteristics (Zhang et al., 2019), meaning findings from Western studies on HME cannot be directly applied to China's cultural context. This study focuses on the relationship between HME and early mathematical abilities, employing meta-analysis to address the following three research questions: 1. What is the strength of the correlation between HME and early MA? 2. How do sub-dimensions of the HME differentially influence early MA? 3. What factors mediate the relationship between the two?

## 2. Method

### 2.1 Literature Search

The literature search comprised two primary strategies. First, a systematic database search was conducted for publications released between January 2010 and May 2025. Papers written in English were identified via PubMed, Taylor & Francis, Wiley, Web of Science, Springer Link, Elsevier Science Direct, ProQuest Dissertations & Theses, and Google Scholar. Search terms for the home mathematics environment included “home mathematics environment,” “home numeracy,” “number activities,” “parent-child interactions,” “math talk,” and “parent expectations.” Terms for early mathematics ability included “early numeracy,” “math skills,” “numeracy,” and “number skills.” Papers written in Chinese were searched in CNKI, VIP, and WanFang Data using corresponding keywords, such as “家庭数学环境” (home mathematics environment), “亲子数学活动” (parent-child math activities), “父母数学期望” (parental math expectations), “早期数学能力” (early mathematical ability), and “数学技能” (mathematical skills).

Second, a backward citation search was implemented by examining the reference lists of all retrieved articles to trace additional relevant literature.

### 2.2 Eligibility Criteria

Literature meeting the study requirements was screened based on the following criteria: 1. Quantitative research, excluding theoretical discussions, qualitative studies, and literature reviews; 2. Clear sample size and measurement tools, requiring the use of specific mathematical assessment instruments such as standardized math tests or researcher-developed math tasks, excluding mixed-discipline or non-mathematical measurement indicators; 3. Studies must report correlation coefficients between HME and MA or provide sufficient data (e.g., F-values, t-values, p-values, etc.); 4. Participants were typically children aged 3–6 years; 5. Studies must explicitly define and measure interactions or resources directly related to mathematics within the home environment, such as family math activities, parental math expectations, or math-related conversations. Ultimately, 82 studies were selected, comprising 71 English-language and 11 Chinese-language articles.

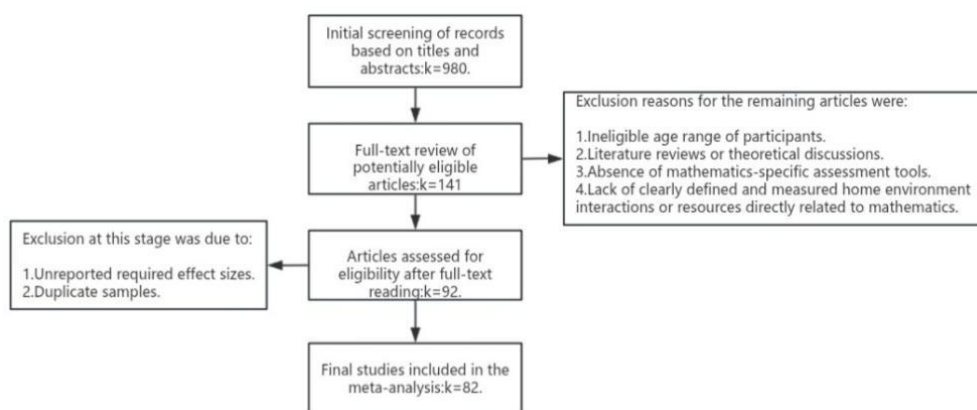


**Figure 1.** Flowchart of Literature Searches and Study Selections

### 2.3 Coding

The selected literature were coded, with required coding features including: author, publication year, document type, cultural background, sample size, participant age, research design, method for measuring HME and MA. An effect size was calculated for each independent sample. If a single document contained multiple independent samples, multiple codings were performed accordingly, yielding multiple independent effect sizes. The coding for this study was performed independently by two authors, achieving 93.4% inter-rater reliability. All coding discrepancies were discussed and resolved through consensus between the two coders.

**Table 1.** Included Studies for Meta-analysis

| Author(s) and year            | Literature Type | Cultural background | N   | Mean Age(months) | Research Design | HME Assessment | MA Assessment |
|-------------------------------|-----------------|---------------------|-----|------------------|-----------------|----------------|---------------|
| Napoli et al., 2025           | Journal         | W                   | 42  | 46.8             | Experimental    | Q              | ST            |
| Melzi et al., 2025            | Journal         | W                   | 73  | 47.21            | Cross-sectional | O              | ST            |
| Outhwaite et al., 2025        | Journal         | W                   | 40  | 45.75            | Cross-sectional | Q              | ST            |
| Kapteijns et al., 2025        | Journal         | W                   | 222 | 65               | Cross-sectional | Q              | ST            |
| King et al., 2025             | Journal         | W                   | 120 | 51               | Cross-sectional | O              | ST            |
| Yılmaz et al., 2025           | Journal         | E                   | 63  | 49.9             | Cross-sectional | Q              | ST            |
| Christian et al., 2025        | Journal         | W                   | 189 | 54               | Longitudinal    | Q              | ST            |
| Tomasetto et al., 2025        | Journal         | W                   | 126 | 57.72            | Longitudinal    | Q              | ST            |
| Mues et al., 2025             | Journal         | W                   | 495 | 60.96            | Longitudinal    | Q              | ST            |
| Lu et al., 2025               | Journal         | E                   | 122 | 62.82            | Cross-sectional | Q、O            | ST            |
| Silver, 2024                  | Thesis          | W                   | 124 | 47               | Longitudinal    | Q              | ST            |
| Sum Kwing Cheung et al., 2024 | Journal         | E                   | 474 | 59.4             | Cross-sectional | Q              | ST            |
| Kwon et al., 2024             | Journal         | W                   | 378 | 54.58            | Cross-sectional | Q              | ST            |
| He, 2024                      | Thesis          | E                   | 37  | 64.8             | Cross-sectional | O              | ST            |
| Zou et al., 2023              | Journal         | E                   | 86  | 44.01            | Longitudinal    | Q、O            | ST            |
| Cosso et al., 2023            | Journal         | W                   | 121 | 54               | Cross-sectional | Q              | ST            |
| Yang et al., 2023             | Journal         | E                   | 90  | 59               | Cross-sectional | Q、O            | ST            |
| Cheung et al., 2023           | Journal         | E                   | 474 | 59.4             | Cross-sectional | Q              | ST            |
| Cheung et al., 2023           | Journal         | E                   | 180 | 55.92            | Cross-sectional | Q              | ST            |

|                               |         |   |          |       |                 |     |     |
|-------------------------------|---------|---|----------|-------|-----------------|-----|-----|
| Bonifacci et al., 2023        | Journal | W | 430      | 69.92 | Cross-sectional | Q   | ST  |
| Pan et al., 2023              | Journal | E | 515      | 60.84 | Cross-sectional | Q   | ST  |
| Girard et al., 2023           | Journal | W | 128      | 67.92 | Cross-sectional | Q   | ST  |
| Wei et al., 2023              | Journal | E | 137      | 57.6  | Cross-sectional | Q   | NST |
| Elliott et al., 2023          | Journal | W | 113      | 64.77 | Longitudinal    | Q   | ST  |
| James-Brabham et al., 2023    | Journal | W | 175      | 44    | Cross-sectional | Q   | ST  |
| Huang et al., 2023            | Journal | E | 96       | 71.46 | Cross-sectional | O   | ST  |
| Leyva et al., 2022            | Journal | W | 146      | 68    | Longitudinal    | Q   | ST  |
| Mues et al., 2022             | Journal | W | 160      | 59.15 | Cross-sectional | Q   | ST  |
| Li, 2022                      | Thesis  | E | 230      | 60    | Cross-sectional | Q   | ST  |
| Chen, 2022                    | Thesis  | W | 131      | 54    | Cross-sectional | Q、O | ST  |
| Camilla et al., 2022          | Journal | W | 163      | 44    | Cross-sectional | Q、O | ST  |
| Wei et al., 2022              | Journal | E | 155      | 67.49 | Longitudinal    | Q   | ST  |
| Cosso et al., 2022            | Journal | W | 148<br>7 | 48.43 | Longitudinal    | Q   | ST  |
| Zou et al., 2022              | Journal | E | 105      | 59.64 | Longitudinal    | Q   | ST  |
| Susperreguy et al., 2022      | Journal | W | 101      | 71    | Longitudinal    | Q   | ST  |
| Bonifacci et al., 2022        | Journal | W | 148      | 64.32 | Cross-sectional | Q   | ST  |
| Rodríguez-García et al., 2022 | Journal | W | 82       | 54    | Cross-sectional | Q   | ST  |
| Anna et al., 2022             | Journal | W | 310      | 59.36 | Longitudinal    | Q   | ST  |
| Silver et al., 2021           | Journal | W | 86       | 47    | Longitudinal    | Q   | ST  |
| Silver et al., 2021           | Journal | W | 90       | 59    | Longitudinal    | Q、O | ST  |
| Leyva et al., 2021            | Journal | W | 78       | 53.19 | Cross-sectional | Q   | ST  |
| Yemimah A et al., 2021        | Journal | W | 125      | 50.04 | Longitudinal    | Q   | ST  |
| Jenni et al., 2021            | Journal | W | 188      | 64.71 | Longitudinal    | Q   | ST  |
| David et al., 2021            | Journal | E | 500      | 57.3  | Longitudinal    | Q   | ST  |
| Paola et al., 2021            | Journal | W | 310      | 56.95 | Longitudinal    | Q   | ST  |
| Guo et al., 2021              | Journal | E | 110      | 54.96 | Longitudinal    | Q   | ST  |
| Mues et al., 2021             | Journal | W | 190      | 69.08 | Longitudinal    | Q   | ST  |
| de León et al., 2021          | Journal | W | 37       | 72    | Cross-sectional | Q   | ST  |
| Susperreguy et al., 2021      | Journal | W | 173      | 56.5  | Cross-sectional | Q   | ST  |
| Susperreguy et al., 2020      | Journal | W | 825      | 55    | Longitudinal    | Q   | ST  |
| Purpura et al., 2020          | Journal | W | 129      | 56.52 | Cross-sectional | Q   | ST  |
| Uscianowski et al., 2020      | Journal | W | 172      | 47.79 | Cross-sectional | Q   | NST |
| Soto-Calvo et al., 2020       | Journal | W | 274      | 48    | Cross-sectional | Q   | ST  |
| Zippert et al., 2020          | Journal | W | 63       | 60.8  | Longitudinal    | Q   | ST  |
| Silver et al., 2020           | Journal | E | 112      | 49    | Longitudinal    | Q   | ST  |
| Jung Lee et al., 2020         | Journal | E | 387      | 66    | Cross-sectional | Q   | ST  |
| Javier et al., 2020           | Journal | W | 212      | 70.08 | Cross-sectional | Q   | ST  |
| Lehrl et al., 2019            | Journal | W | 554      | 44.57 | Longitudinal    | Q   | ST  |
| Yildiz et al., 2018           | Journal | W | 128      | 65.12 | Cross-sectional | Q   | ST  |

|                               |         |   |           |       |                 |   |     |
|-------------------------------|---------|---|-----------|-------|-----------------|---|-----|
| Yildiz et al., 2018           | Journal | W | 44        | 67.68 | Cross-sectional | O | NST |
| Napoli et al., 2018           | Journal | W | 114       | 49.08 | Longitudinal    | Q | ST  |
| Luo, 2018                     | Thesis  | E | 177       | 68.63 | Cross-sectional | Q | ST  |
| del Rio et al., 2017          | Journal | W | 178       | 67.2  | Cross-sectional | Q | ST  |
| Huang et al., 2017            | Journal | E | 104       | 59.7  | Cross-sectional | Q | ST  |
| Cheung et al., 2017           | Journal | E | 673       | 51.11 | Cross-sectional | Q | ST  |
| Elliott et al., 2017          | Journal | W | 46        | 69.55 | Cross-sectional | O | ST  |
| Thompson et al., 2016         | Journal | W | 184       | 42.48 | Cross-sectional | Q | ST  |
| Susperreguy et al., 2016      | Journal | W | 35        | 67.43 | Longitudinal    | O | ST  |
| Niklas et al., 2016           | Journal | W | 113       | 53.7  | Longitudinal    | Q | ST  |
| Niklas et al., 2016           | Journal | W | 168<br>6  | 67    | Longitudinal    | Q | ST  |
| Benavides-Varela et al., 2016 | Journal | W | 111       | 71.4  | Cross-sectional | Q | ST  |
| Huntsinger et al., 2016       | Journal | W | 97        | 70.56 | Longitudinal    | Q | ST  |
| Niklas et al., 2015           | Journal | W | 106       | 53    | Longitudinal    | Q | ST  |
| Ramani et al., 2015           | Journal | W | 33        | 52    | Cross-sectional | Q | ST  |
| Puccioni et al., 2015         | Journal | W | 126<br>22 | 72    | Longitudinal    | Q | ST  |
| Liu, 2015                     | Thesis  | E | 134       | 65.84 | Cross-sectional | Q | ST  |
| Pan et al., 2019              | Journal | E | 220       | 61.57 | Cross-sectional | Q | ST  |
| Yang et al., 2019             | Journal | E | 221       | 61.59 | Cross-sectional | Q | ST  |
| Shan, 2021                    | Thesis  | E | 308       | 54    | Cross-sectional | Q | ST  |
| Zhu, 2022                     | Thesis  | E | 180       | 62.26 | Cross-sectional | Q | ST  |
| Tang, 2022                    | Thesis  | E | 153       | 67.9  | Cross-sectional | Q | ST  |

Note. N = sample size; W = Western culture; E = Eastern culture; Q = Questionnaire; O = Observation; ST = Standardized Test; NST = Non-standardized Test.

## 2.4 Calculation and Analysis of Effect Sizes

Select the  $r$  value as the effect size. If the  $r$  value was not reported in the literature, convert using the  $t/d/\beta/\eta^2/OR$  values reported within the literature. The conversion formula is as follows (Lenhard, 2016):  $r = \beta * 0.98 + 0.05\lambda$  (When  $-0.5 < \beta < 0$ ,  $\lambda = -1$ ; when  $0 < \beta < 0.5$ ,  $\lambda = 1$ );  $r = \sqrt{\frac{d^2}{d^2+4}} = \sqrt{\frac{t^2}{t^2+df}} = \sqrt{\eta^2}$ ;  $d = \ln\left(\frac{OR}{\pi}\right) \frac{\sqrt{3}}{\pi}$ . If multiple effect sizes were reported within the same study and the corresponding research samples were independent of each other, each effect size was recorded as an independent sample. If the study did not report the effect size for the total problem behavior but instead reported effect sizes for individual subscales, the mean was taken as the initial effect size. Using the above method, 174 independent effect sizes were ultimately obtained, involving 30,550 participants.

## 2.5 Data Analysis

Data processing was performed using CMA 3.0 (Comprehensive Meta-Analysis 3.0).

## 3. Results

### 3.1 Publication Bias

The results of the publication bias assessment are shown in Figure 2. The funnel plot indicated that the vast majority of effect sizes included in the meta-analysis are relatively uniformly and symmetrically distributed on both sides of the mean effect size, with most study effect sizes clustering in the upper-middle portion of the "inverted funnel". The fail-safe  $N$  was 4925,  $p < 0.05$ , which was significantly greater than the critical value of  $5k + 10$  (in this study,  $k = 139$ ). Additionally, the results of Egger's linear regression test indicated that  $p = 0.000 < 0.05$ . Collectively, these findings suggest a low probability of publication bias in the present study.

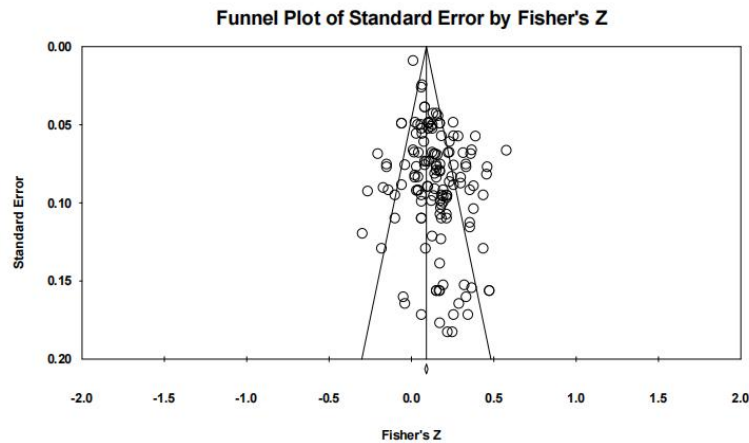


**Figure 2.** Publication Bias Funnel Plot

### 3.2 Heterogeneity Testing

This study employed the Q-test and  $I^2$  test to assess the variability among the included meta-analysis studies. The Q-value represents the heterogeneity statistic, while  $I^2$  denotes the proportion of total effect size variation that is attributable to heterogeneity. The heterogeneity test results (see Table 2) showed that  $Q = 596.488$ ,  $p < 0.05$  and  $I^2 = 76.865\%$ , indicating substantial heterogeneity among the included effect sizes. Consequently, a random-effects model was adopted for effect size pooling, and this heterogeneity suggests that the variation in effect sizes is influenced by specific moderating variables, thereby necessitating further secondary meta-analysis.

**Table 2.** Heterogeneity Test

| Model                | $k$ | $n$   | 95% CI |       | $Q$ -value | $df(Q)$ | Heterogeneity |        |         |
|----------------------|-----|-------|--------|-------|------------|---------|---------------|--------|---------|
|                      |     |       | LL     | UL    |            |         | $p$ -value    | $I^2$  | $Tau^2$ |
| Random-effects model | 139 | 28975 | 0.117  | 0.163 | 596.488    | 138     | 0.000         | 76.865 | 0.013   |

### 3.3 Correlations between the HME and Its Sub-Dimensions with Early Mathematical Ability

The random effects model analysis revealed (see Table 3) that the overall correlation coefficient between the home mathematical environment and children's early mathematical abilities was 0.140 ( $p < 0.001$ ). Among the sub-dimensions, correlation coefficients ranged from -0.122 to 0.239. Ranked in descending order of correlation coefficients: parental mathematical beliefs > family mathematical activities > parental mathematical attitudes > parental mathematical expectations > parental mathematical discourse > parental mathematical anxiety. All correlations reached statistical significance except for parental mathematical discourse. According to effect size criteria (Gignac & Szodorai, 2016), the overall home mathematics environment exhibited a moderate positive correlation with early mathematical ability. The correlation between parental mathematical beliefs and early mathematical ability reached an upper-moderate level. Home mathematics activities showed a moderate positive correlation with parental mathematical attitudes. Parental mathematical expectations and parental mathematical discourse demonstrated low to moderate correlations, while parental mathematical anxiety exhibited a moderate negative correlation.

**Table 3.** Random Effects Model Analysis

| Variable                   | $k$ | $n$   | $r$    | 95% CI |        | Two-tailed test |            |
|----------------------------|-----|-------|--------|--------|--------|-----------------|------------|
|                            |     |       |        | LL     | UL     | Z-value         | $p$ -value |
| Home Math Environment      | 139 | 28975 | 0.140  | 0.117  | 0.163  | 11.729          | 0.000      |
| Home Math Activities       | 77  | 27552 | 0.184  | 0.154  | 0.214  | 11.680          | 0.000      |
| Parental Math Attitudes    | 16  | 3552  | 0.110  | 0.080  | 0.139  | 7.250           | 0.000      |
| Parental Math Discourse    | 14  | 1655  | 0.067  | -0.022 | 0.155  | 1.479           | 0.139      |
| Parental Math Expectations | 13  | 2886  | 0.108  | 0.033  | 0.182  | 2.823           | 0.005      |
| Parental Math Anxiety      | 11  | 1202  | -0.122 | -0.173 | -0.069 | -4.545          | 0.000      |
| Parental Math Beliefs      | 8   | 930   | 0.239  | 0.109  | 0.361  | 3.559           | 0.000      |

### 3.4 Moderation Effect Analysis

This study employed subgroup analysis to examine the moderating effects on the association strength between home math environment and early mathematical ability in young children, including: (1) sub-dimensions of home math environment; (2) different cultural backgrounds; (3) different research designs; (4) different measurement methods; (5) different assessment tools.

### 3.4.1 Sub-dimensions of Home Math Environment

Based on the definition of the home math environment, this study grouped it into six categories: home mathematical activities, parental mathematical attitudes, parental mathematical conversations, parental mathematical expectations, parental mathematical anxiety, and parental mathematical beliefs. Subgroup analysis revealed (see Table 4) that the moderating effect of different dimensions of the home math environment on its relationship with early mathematical ability was significant,  $Q = 102.296, p < 0.001$ . Among these, parental mathematical beliefs exerted the strongest positive association with early mathematical ability,  $r = 0.239, p < 0.001$ . This was followed by family mathematical activities, which showed a significant positive correlation with early mathematical ability,  $r = 0.184, p < 0.001$ . Parental mathematical anxiety exhibited a significant negative correlation with early mathematical ability,  $r = -0.122, p < 0.001$ . The associations between early mathematical ability and parental mathematical attitudes ( $r = 0.110, p < 0.001$ ) as well as parental mathematical expectations ( $r = 0.108, p = 0.005$ ) were comparatively weaker but still significant. The correlation between parental mathematical discourse and early mathematical ability was non-significant ( $r = 0.067, p = 0.139$ ).

**Table 4.** Effectiveness Test of the Influence of HME on Early mathematical Ability

| Variable                   | <i>k</i> | <i>n</i> | <i>r</i> | 95% CI |        | Two-tailed test |                 |
|----------------------------|----------|----------|----------|--------|--------|-----------------|-----------------|
|                            |          |          |          | LL     | UL     | Z-value         | <i>p</i> -value |
| Home Math Activities       | 77       | 27552    | 0.184    | 0.154  | 0.214  | 11.680          | 0.000           |
| Parental Math Beliefs      | 8        | 930      | 0.239    | 0.109  | 0.361  | 3.559           | 0.000           |
| Parental Math Expectations | 13       | 2886     | 0.108    | 0.033  | 0.182  | 2.823           | 0.005           |
| Parental Math Discourse    | 14       | 1655     | 0.067    | -0.022 | 0.155  | 1.479           | 0.139           |
| Parental Math Attitudes    | 16       | 3552     | 0.110    | 0.080  | 0.139  | 7.250           | 0.000           |
| Parental Math Anxiety      | 11       | 1202     | -0.122   | -0.173 | -0.069 | -4.545          | 0.000           |

### 3.4.2 Different Cultural Backgrounds

This study categorized participants based on the sociocultural context of the early childhood settings across research studies, dividing them into Eastern and Western groups. Results indicated (see Table 5) that cultural background significantly moderated the relationship between home math environment and early mathematical ability,  $Q = 4.673, p = 0.031$ . Within the Eastern cultural context, the correlation coefficient was  $r = 0.181, p < 0.001$ ; within the Western cultural context, the correlation coefficient was  $r = 0.121, p < 0.001$ . Findings indicate that the promotional effect of the home math environment on early mathematical ability is more pronounced within Eastern cultures.

### 3.4.3 Different Research Designs

This study employed both cross-sectional and longitudinal designs based on the research frameworks of individual studies. Subgroup analyses revealed (see Table 5) that the moderating effect of research design on the relationship between home math environment and early mathematical ability was significant,  $Q = 8.230, p = 0.004$ . In the longitudinal study, the correlation coefficient was  $r = 0.099, p < 0.001$ ; in the cross-sectional study, the correlation coefficient was  $r = 0.163, p < 0.001$ . This indicates that the effect of the home math environment on early mathematical ability was stronger in cross-sectional studies than in longitudinal studies.

### 3.4.4 Different Measurement Method

This study categorized measurement methods for the home math environment into questionnaire and observation approaches. Subgroup analysis revealed (see Table 5) that the measurement method did not significantly moderate the relationship between the two variables, with  $Q = 0.678, p = 0.410$ .

### 3.4.5 Different Assessment Tools

This study categorized the assessment tools for early mathematical ability used in each study into standardized and non-standardized groups. Subgroup analysis revealed (see Table 5) that the assessment tool for early mathematical ability did not significantly moderate the relationship between home math environment and early mathematical ability,  $Q = 0.412, p = 0.521$ .

**Table 5.** Moderating Effects of Related Factors on HME and Early Math Ability

| Moderation Variable   | Category                   | <i>k</i> | <i>r</i> | 95% CI |        | Two-tailed test |                 | <i>Q</i> -value | <i>p</i> -value |
|-----------------------|----------------------------|----------|----------|--------|--------|-----------------|-----------------|-----------------|-----------------|
|                       |                            |          |          | LL     | UL     | Z-value         | <i>p</i> -value |                 |                 |
| HME Different Factors | Home Math Activities       | 77       | 0.184    | 0.154  | 0.214  | 11.680          | 0.000           | 102.296         | 0.000           |
|                       | Parental Math Beliefs      | 8        | 0.239    | 0.109  | 0.361  | 3.559           | 0.000           |                 |                 |
|                       | Parental Math Expectations | 13       | 0.108    | 0.033  | 0.182  | 2.823           | 0.005           |                 |                 |
|                       | Parental MathDiscussions   | 14       | 0.067    | -0.022 | 0.155  | 1.479           | 0.139           |                 |                 |
|                       | Parental Math Attitudes    | 16       | 0.110    | 0.080  | 0.139  | 7.250           | 0.000           |                 |                 |
|                       | Parental Math Anxiety      | 11       | -0.122   | -0.173 | -0.069 | -4.545          | 0.000           |                 |                 |
| Cultural background   | Western                    | 98       | 0.121    | 0.096  | 0.146  | 9.382           | 0.000           | 4.673           | 0.031           |
|                       | Eastern                    | 41       | 0.181    | 0.133  | 0.229  | 7.226           | 0.000           |                 |                 |
| Study Design          | Longitudinal               | 48       | 0.099    | 0.071  | 0.127  | 6.938           | 0.000           | 8.230           | 0.004           |
|                       | Cross-sectional            | 91       | 0.163    | 0.130  | 0.195  | 9.529           | 0.000           |                 |                 |
| Measurement Method    | Questionnaire              | 109      | 0.146    | 0.120  | 0.171  | 11.211          | 0.000           | 0.678           | 0.410           |
|                       | Observation                | 30       | 0.117    | 0.053  | 0.180  | 3.562           | 0.000           |                 |                 |
| Evaluation Tool       | Standardisation            | 128      | 0.137    | 0.114  | 0.160  | 11.499          | 0.000           | 0.412           | 0.521           |
|                       | Non-standardised           | 11       | 0.182    | 0.043  | 0.315  | 2.560           | 0.010           |                 |                 |

## 4. Discussion

### 4.1 The Relationship Between HME and Early Mathematical Ability

This study synthesised 82 research projects, employing meta-analysis to quantitatively assess existing evidence and further clarify their relationship. Findings revealed a moderate positive correlation between home math environment and early mathematical ability, consistent with prior research (Daucourt et al., 2021). This indicates that a favourable home math environment supports the development of young children's mathematical abilities. This finding supports the core tenets of sociocultural theory, which posits that the family serves as the primary microsystem for early childhood development. Through diverse means—such as participation in mathematical activities, transmission of attitudes, and linguistic interaction—parents construct cognitive scaffolding that effectively facilitates children's internalisation and construction of mathematical knowledge (LeFevre et al., 2009). However, the home math environment accounts for only approximately 4% of the variance in mathematical ability, indicating that early mathematical ability development is influenced by multiple factors. This aligns with the ecological systems theory, which emphasises that early childhood development is shaped by the interaction of multiple systems, requiring the home to collaborate with systems such as schools and communities.

Compared to prior research, the present findings exhibit weaker correlations than some single-study reports, such as the correlation coefficient of 0.35 (Skwarchuk et al., 2014). However, this discrepancy aligns precisely with the meta-analytic pattern of "shrinkage" in true effect sizes, suggesting individual studies may overestimate association strength due to sample bias or uncontrolled confounding variables (Borenstein et al., 2021). This further underscores the necessity and importance of synthesising multiple studies to assess true effect values, as relying solely on a single study risks misjudging the genuine relationship between variables.

### 4.2 The Effects of Different HME Components

This study found significant differences in the impact of distinct sub-dimensions of the home math environment on early mathematical ability, further validating the multi-faceted structure and heterogeneous characteristics of this environment. Among these, the positive effect of parental mathematical beliefs was most pronounced, indicating that parents' convictions regarding the plasticity of mathematical ability and their own educational efficacy significantly promote young children's mathematical development. According to social cognitive theory, parental beliefs regarding mathematical ability, plasticity, and self-efficacy directly translate into more proactive educational engagement. This influences the manner and frequency with which they engage in mathematics-related activities with young children at home (Susperreguy et al., 2025), thereby creating a more supportive mathematical learning environment that substantially enhances children's ability development.

Parental mathematical anxiety, conversely, exhibited a significant negative predictive effect, consistent with prior research findings. On the one hand, parents with higher anxiety levels tend to adopt controlling behaviours when engaging in mathematical learning with young children (Oh et al., 2022; Retanal et al., 2021), frequently negating and correcting children's independent exploratory actions (Çarkoğlu & Eason, 2025), thereby diminishing children's interest in mathematical exploration. Conversely, anxious parents often avoid mathematical interactions or convey negative attitudes towards learning mathematics (DiStefano et al., 2020). This undermines children's autonomy and willingness to engage in mathematical learning, fostering negative emotions towards the subject (Chang & Beilock, 2016). This finding indirectly highlights the significance of parental emotional regulation within the home math environment, while also corroborating emotional contagion theory – a concept further substantiated in research concerning mathematical anxiety (Chang & Beilock, 2016).

Notably, the effect of parental mathematical discourse did not reach statistical significance, indicating that such discourse does not significantly influence young children's mathematical ability development. This finding challenges existing research, which has predominantly suggested that parental mathematical language significantly impacts children's mathematical learning (Casey et al., 2018; Ramani et al., 2015; Betts & Son, 2020; Susperreguy & Davis-Kean, 2016). However, recent intervention studies indicate that increasing parental mathematical language input does not significantly enhance young children's mathematical ability development (Lu et al., 2025). This may occur because overemphasising the quantity of mathematical language input in parent-child interactions could potentially undermine parental autonomy support, thereby producing a counterproductive effect on children's engagement.

### 4.3 The Moderating Effects on the Relationship Between HME and Early Math Ability

This study examined the moderating effects of cultural background, research design, methods for measuring the home math environment, and tools for assessing early mathematical ability on the relationship between the home math environment and early mathematical ability, aiming to clarify the factors influencing this relationship. Results indicate that cultural background and research design exerted significant moderating effects on this relationship, whereas methods for measuring the home math environment and tools for assessing early mathematical ability had no significant impact on the relationship.

#### 4.3.1 Cultural Background.

Cultural background exerted a significant moderating effect on the relationship between the home math environment and early math ability, specifically manifested in the fact that the association was significantly stronger in Eastern cultural contexts than in Western ones. This phenomenon can be attributed to cultural differences between East and West. Sociocultural theory posits that individual cognitive development originates from and is closely dependent on social, cultural, and other factors, and young children's early math cognition may vary across different sociocultural contexts. Driven by both Confucian cultural traditions and a socially competitive atmosphere, Eastern families attach great importance to young children's academic achievement, particularly math ability (Ho et al., 2000). Eastern parents generally regard math achievement as a core indicator of academic performance and hold high expectations for their children's math development (Luo et al., 2013). With this cognition, parents perceive promoting their children's math ability as a core family responsibility rather than relying solely on school education, thereby proactively investing more time, resources, and emotional support in the home math environment. Empirical studies have confirmed that parents in Eastern countries such as China and India actively initiate more targeted home mathematics activities, such as number symbol recognition, numerical operation practice, and math problem-solving (Huang et al., 2017). Through these targeted interactions, they strengthen the positive driving effect of the home mathematics environment on young children's math ability, constructing a strong association pathway between the two.

Differences in parenting styles between Eastern and Western families further exacerbate the cross-cultural divergence in the strength of the aforementioned association. Compared with the Western "autonomous" parenting model, Eastern families are more inclined to adopt an "authoritative" or "intensive" parenting style, emphasising high investment, high expectations, and high responsiveness to their children (Chao, 2001). Under this parenting model, Eastern parents' involvement is more "learning-oriented" (Cheung & Pomerantz, 2011), home mathematics activities are more goal-directed and planned (Huang et al., 2017), and the directionality and quality of parent-child math talk are significantly higher. This renders the home mathematics environment highly structured, thereby more effectively promoting the development of young children's early math ability.

#### 4.3.2 Research Design.

Research design also played a significant moderating role in the relationship between the home math environment and early math ability: compared with longitudinal studies, cross-sectional studies showed a stronger correlation between the home mathematics environment and early math ability. From the perspective of developmental mechanisms, the impact of the home mathematics environment on young children's math ability has an immediate effect. Cross-sectional studies can accurately capture the direct promotional effect of the family environment on young children's math ability at specific developmental stages. In contrast, during longitudinal tracking, the development of young children's math ability is gradually influenced by multiple additional factors, such as the maturation of cognitive abilities like executive function (Chan & Scalise, 2022) and the intervention of systematic math teaching in kindergartens (Miller et al., 2023). The involvement of these subsequent variables dilutes the weight of early family influences, thereby weakening the

observed association between the two in longitudinal studies. Secondly, the home mathematics environment is not a static variable. Existing research has shown that the types and frequency of math activities conducted in families dynamically adjust as children grow older, and their predictive power for children's math development varies significantly across different time points (Thompson et al., 2017; Chen, 2018). Cross-sectional studies are more likely to focus on the concentrated effect at a specific age, thus more easily observing a stronger local association between the two. Additionally, longitudinal studies require multiple repeated measurements, which are prone to cumulative measurement errors. The random components of such errors can interfere with the true association between variables, further weakening the correlation between the home mathematics environment and early math ability in longitudinal studies.

## 5. Limitations and Future Research

This study examined the relationship between HME and MA and explored the moderating effects of cultural background and research design on this relationship. Nevertheless, several limitations should be acknowledged. First, the present study focused on the associations between HME and MA and therefore could not establish causal relationships between the two variables. Future research should employ intervention or experimental designs to further clarify the causal mechanisms underlying the relationship between HME and MA. Second, due to the limited number of studies reporting results separately for boys and girls, gender could not be included as a moderating variable in the current analysis. Future studies should explore whether the effects of HME on MA differ across gender groups. Third, although significant moderating effects of cultural background and research design were identified, other potentially important factors—such as socioeconomic status, parental education level, and children's age—could not be examined due to insufficient reporting in the primary studies. Future meta-analyses should investigate these variables to better understand the mechanisms and boundary conditions underlying the relationship between HME and early mathematical ability.

## 6. Conclusions

This meta-analysis demonstrated that the home math environment is a significant positive predictor of early mathematical ability. Cultural background and research design moderated the strength of this relationship. With a focus on the subdimensions of the home math environment, parental math beliefs and home math activities had the strongest positive associations with early mathematical ability, whereas parental math anxiety negatively predicted children's mathematical development. Overall, a positive and supportive home math environment may contribute to the development of young children's mathematical abilities.

## Data Availability Statement

The dataset generated and analyzed during the current study is available from the corresponding author upon request.

## Conflicts of interest

The authors declare no conflict of interest.

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