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A Meta-Analysis of Math Anxiety Interventions

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Supplementary Materials: Materials [see Index of Supplementary Materials]

Abstract

The experience of math anxiety can have detrimental effects on students' math performance, and researchers have in recent years tried to design interventions aiming at reducing math anxiety. This meta-analysis aimed to examine the effectiveness of math anxiety interventions in reducing math anxiety and improving math performance. The meta-analysis comprised 50 studies and included 75 effect sizes. On average, the effect sizes were moderate (g = -0.467) for reducing math anxiety and improving math performance (g = 0.502). Interventions that focused on Cognitive support or regulating Emotions were effective both in reducing math anxiety and improving math performance. In addition, longer interventions and interventions targeting students older than 12 had the biggest decrease in math anxiety. Study quality was not related to intervention outcomes.

Keywords

intervention, math anxiety, math performance, meta-analysis

MA has been identified as a form of anxiety that occurs when a person is asked to think about or complete a math task, which in turn causes a negative physical-emotional reaction (Lee, 2009), such as feeling tense, nervous, and scared (Luttenberger et al., 2018). While it is common to feel anxious when asked to complete a high-demanding math test, it can for students with MA be highly stressful to perform everyday tasks, such as entering a math classroom, opening a math textbook, reading a receipt at the store as well as if asked to read math equations out loud (Ashcraft & Moore, 2009; Maloney & Beilock, 2012). These feelings can lead to avoidance for situations where they are expected to use their mathematical skills, and by extension, some will even avoid math-related career opportunities (Ashcraft & Krause, 2007). Consequently, math anxiety is also negatively related to math performance (Namkung et al., 2019).

Three different theoretical accounts have been put forward to explain the link between math anxiety and math performance. The first is the *Deficit Theory*, which implies that low math achievement causes high math anxiety (Sorvo et al., 2019). The second model, the *Debilitating Anxiety Model*, implies that math anxiety impairs math performance (Carey et al., 2016), either through avoidance of math-related situations (Choe et al., 2019) or, directly through cognitive interference when processing and retrieval of numerical information (Finell et al., 2022). The third, the *Reciprocal Model*, suggests a combination of the prior two theories (Gunderson et al., 2018; Ma & Xu, 2004). As the research findings on the causal relationship between math anxiety and math performance are inconclusive, it is still an open question if it would be more beneficial to focus interventions on reducing math anxiety (debilitating anxiety theory), or enhancing math performance (deficit theory), or both (reciprocal theory).

In previous research, three main categories can be distinguished that are often used by researchers to manipulate or reduce math anxiety: 1) Motivation, 2) Emotion, and 3) Cognitive support. The first category focuses on interventions attempting to increase the participants' motivation, for example, by offering different or exciting learning opportunities or by including feedback or other motivating elements in their learning. Two theories are usually mentioned in the context of motivational processes in mathematics learning: 1) *Expectancy-Value theory* and 2) *Self-Determination theory.* According to the first theory, expectations of success and subjective task value influence a person's engagement in a subject, achievement, and choices (Eccles & Wigfield, 2002). The second theory suggests that humans have ingrained psychological needs regarding competence, autonomy, and social relatedness, and will, as a result, develop inherent motivation (Schukajlow et al., 2017).

The second category includes interventions aiming to reduce math anxiety by affecting the participants' emotions toward math. This is achieved through regulating or changing participants' emotions by implementing therapy, relaxation exercises, writing exercises, etc. Positive emotions, such as enjoyment and pride, are often associated with greater interest and achievement in math, while negative emotions can lead to more restricted cognitive and behavioral responses, e.g., issues with problem-solving and thinking processes (Villavicencio & Bernardo, 2016). The emotion category could be seen as reflecting the debilitating anxiety model as interventions in this category focus on regulating the emotions that arise in engaging in math activities (Carey et al., 2016).

The third and final category consists of interventions that focus on decreasing math anxiety by providing cognitive support. The category draws on the findings that cognitive resources such as working memory, problem-solving and executive functioning are prerequisites for expanding the acquisition of math facts, and number sense – crucial in the context of math development and learning (Kroeger et al., 2012). The Cognitive support category consists of interventions where the researchers try to change the participants' learning strategies, providing different kinds of instructions, handing out tutorials, or offering the participants the opportunity to complete tasks using tools (e.g., calculators etc.). These interventions aim primarily to enhance task performance when engaging in math activities, thus aligning more with the deficit theory (Sorvo et al., 2019).

Research has shown that math anxiety tends to increase with age (Dowker et al., 2016; Wang et al., 2021), and as pointed out in longitudinal studies this often coincides with a decline in students' interest in math as they get older (e.g., Barroso et al., 2021; Namkung et al., 2019; Zhang et al., 2019). Based on these findings it is plausible to expect that it could be more beneficial to target math anxiety interventions for older students. In math performance research, interventions that vary in the number of sessions and length have been conducted, yet it is still unclear if there is a preferred design to utilize when executing an intervention, as shorter interventions with fewer sessions can be equally efficient as longer ones (DeFouw et al., 2021). For example, Schnepel and Aunio (2022) concluded in their review that the most efficient interventions were those that consisted of at least two sessions per week, while other researchers endorse interventions that are intensified in terms of session length and duration, and that are offered up to four times per week to increase the likelihood of progress (DeFouw et al., 2021). However, in the domain of math anxiety interventions, no previous studies have investigated the effect of intervention length in reducing math anxiety.

A handful of reviews and one meta-analysis have analyzed the impact of math anxiety-interventions on math anxiety. Balt et al. (2022) found in their review that math anxiety-interventions that consist of educational games or formalized math programs, can reduce math anxiety-responses, and give participants an opportunity to re-evaluate their beliefs about their own abilities. In a review, by Ramirez et al. (2018), reappraisal and expressive writing were identified as efficient methods for reducing MA, while Luttenberger et al. (2018) found that methods involving positive learning are beneficial for reducing math anxiety, for example, by focusing on previous successes rather than failures, or by implementing "drill and practice" and avoiding procrastination. Petronzi et al. (2021) analyzed various interventions in their review, and the results suggest that interventions that promote cognitive control with a focus on emotional regulation and attentional processes are the most efficient. In the only previous meta-analysis, Dondio et al. (2022) explored the effectiveness of game-based interventions in reducing math anxiety. The overall effect size was small and non-significant, indicating that game-based interventions did not reduce math anxiety.

No previous meta-analysis has systematically synthesized all published interventions aimed at reducing math anxiety.

Thus, in a meta-analysis, the present study aimed to advance the current knowledge base by synthesizing the existing research on interventions that aim to reduce math anxiety. It is recommended that study quality should be a vital part of a meta-analysis, it helps explain heterogeneity across observed effect sizes and enables a more accurate determination of the weighted mean effect size across replication studies (Feeley, 2020). Consequently, we utilized the Quality Assessment Tool for Quantitative Studies from the Effective Public Health Practice Project (EPHPP; Thomas et al., 2004) to evaluate the quality of the included articles and also examined its potential moderating effect on the results. Therefore, the research questions were (I) How effective are the interventions at reducing participants' math anxiety? (II) How effective are the interventions at improving participants' math performance? (III) Does age, intervention category, intervention length, and study quality moderate the effectiveness of interventions on these outcomes?

Method

Literature Search

The present meta-analysis followed Cooper et al. (2019) recommendation that systematic reviews should encompass multiple databases and that those databases are described in the article. It should also include transparency regarding the search criteria and the different decisions made during the process. This approach allows for a backward search which refers to the process of identifying and reviewing the reference lists of articles that have already been retrieved to find additional relevant articles. The articles for this study were collected via searches on the following databases: Medline, ERIC, APA PsycInfo, APA PsycArticles, Academic Search Complete, Business Source Ultimate and Teacher Reference Center and only included studies aiming to reduce students' math anxiety. The search was completed in March 2021, and included articles published and peer-reviewed before the search took place. We didn't set a time interval, which led to no restrictions regarding the age of the articles. The choice of keywords was guided by the PICO framework (Richardson et al., 1995), and were:

> "*math anxiety*" OR "*mathematics anxiety*"
> AND
> "*performance*" OR "*achievement*" OR "*success*"
> AND
> "*intervention*" OR "*study*" OR "*test*"

We then included search criteria to help us locate studies that we needed for the analysis.

Inclusion and Exclusion Criteria

a. Peer-reviewed studies, published in academic journals, written in English, published before the end of March 2021, and aimed to reduce math anxiety were included. No study was excluded based on the outcome.
b. Intervention studies with and without control groups were included, accompanied by at least means and standard deviations, allowing us to calculate standardized mean effects.
c. However, studies of math anxiety with no intention to reduce math anxiety and those focused on reducing anxiety in other domains were excluded. Studies that only explored how math performance was enhanced were also excluded.

Coding

For Research Questions I and II we extracted information on sample sizes, means and standard deviations for both math anxiety and math performance measures. We analyzed posttest scores for control- and treatment groups, but for studies with only one group, we treated pretest scores as the control. These were used to calculate the standardized mean difference. Further, for our moderation analyses (Research Question III) we also collected information on sample characteristics, such as mean age, and on intervention characteristics, such as intervention theme and length. Articles reporting interventions that were arranged once and lasted no longer than one day were considered Short. Articles with interventions that lasted more than a day but not longer than three weeks were considered Medium. The final category, Long, consisted of interventions with a duration of longer than three weeks. By coding each article independently, and then assessing the results together, we wanted to reduce the risk of biased treatment. Disagreements were discussed and evaluated by authors ES and JF, and co-authors (BJ and JK) were consulted when necessary. See Table S1 in the Supplementary Materials for a summary of studies included in the meta-analysis, which entails data regarding moderator variables, effect sizes, and study quality scores. Lastly, every article was assigned to one of the three intervention categories: 1) Motivation, 2) Emotion, and 3) Cognitive support. See Table S2 in the Supplementary Materials for a description of every article's intervention and how they were assorted into categories.

All included articles were read in full text and evaluated using EPHPP (Thomas et al., 2004) to examine the quality of every article. The EPHPP tool provides a standardized procedure for examining the quality of intervention studies. The tool consists of eight different sections related to study quality (e.g., selection bias; study design; data collection methods; withdrawals and drop-outs) and every section in turn contains questions against which each individual article is assessed and numerically graded. By calculating the mean section score from the question grades, the article under evaluation gets a quality rating of either 1) strong, 2) moderate or 3) weak for each of the eight EPHPP sections. The section quality ratings are then used to arrive at a final classification of the quality of the article. Articles with ≥ 4 strong ratings were classified as "strong", while articles with ≥ 3 weak ratings were classified as "weak". Articles with ≤ 3 strong ratings and < 3 weak ratings were classified as "moderate".

Interrater Reliability

Our search resulted in a final sample of 1686 studies which were screened by authors ES and JF. An additional study, which was found by one of the authors through his research network, was added to the search. After screening the 1687 abstracts, a sample of 91 articles remained. An interrater reliability measure proved substantial agreement between the authors' ES and JF (k = 0.80). Disagreements were discussed, and co-authors (BJ and JK) were consulted when necessary.

91 articles underwent a full-text assessment. Articles that did not meet our chosen inclusion criteria or failed to contribute with the statistical measures needed for the analyses, were excluded. ES and JF agreed upon a total of 50 studies that were included for the final analyses (k = 0.79). The 50 studies analyzed the interventions' effect on math anxiety, but only 30 explored how math performance was improved. See Figure 1.

Concerning study quality, authors (ES and JF) analyzed each article individually and agreed upon a final rating for each article. Disagreements between the authors were resolved by consulting co-authors BJ and JK.

Data Analysis

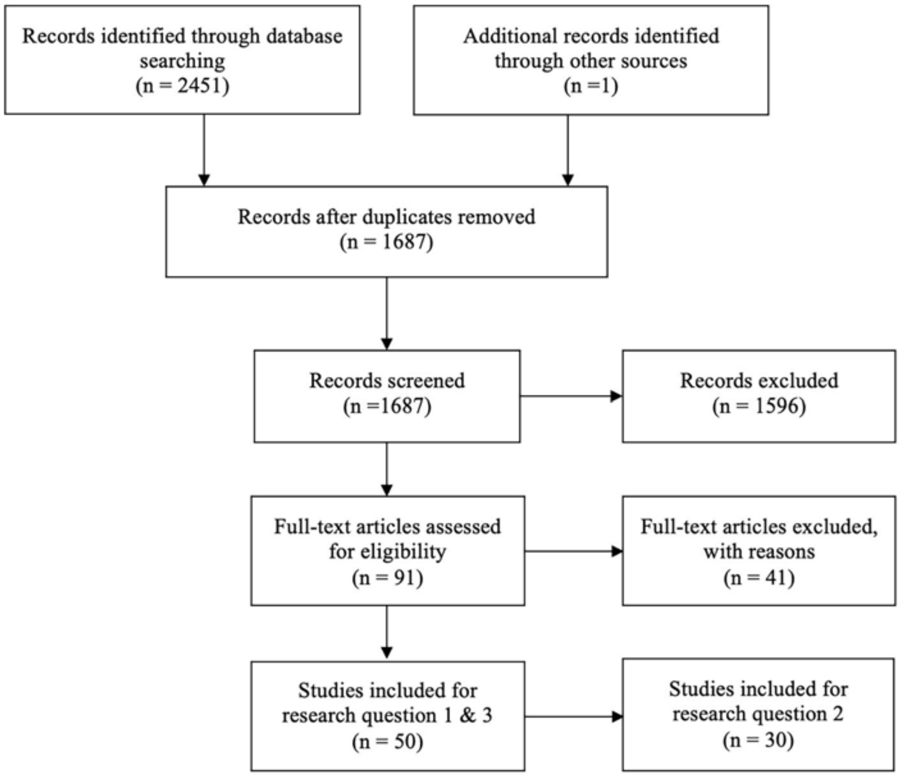
To answer our three research questions, how math anxiety interventions can reduce math anxiety and increase math performance, it was decided to investigate math anxiety and math performance separately. We conducted Cochran's Q test, which is a test to determine heterogeneity in a meta-analysis. Q tests were significant (p < .001). Based on the results from the Q test, and that factors such as age, and treatment are drawn from different populations and thus vary a lot, it was decided that a random-effects model was more suitable than a fixed-effects model. By using the random-effects model, you assume a distribution of true effect sizes, and calculate the mean of the distribution (Borenstein et al., 2010). We used the meta-package in R (Schwarzer, 2007) to perform all analyses. Regarding our first research question, intervention effects on math anxiety, 16% of the studies consisted of a 1 cohort pre-post design without a control group. The studies were kept as it's preferable to the alternative − dismissing them altogether (Borenstein et al., 2010). The data from studies without control groups, were prepared according to recommendations from Cooper et al. (2019). All effect sizes were adjusted with the correction J-factor resulting in Hedge's g effect sizes.

Evaluation of Publication Bias

We decided to evaluate publication bias by implementing two methods: A funnel plot and Egger's test. A funnel plot gives a demonstrative view of all the effect sizes in the data and reveals publication bias in the study (Simmonds, 2015). The second method, the Egger's test, is a formal test for asymmetry in funnel plots that calculates the regression of study effect sizes on their standard errors (Egger et al., 1997).

Figure 1

Prisma Flow Diagram



Results

Overall Analysis

To assess the effectiveness of the interventions on participants' math anxiety (RQ1), we calculated the mean of our 75 effect sizes from our 50 studies, including a total sample size of 9,125 participants. The pooled interventions resulted in a significant standardized mean difference (g = -0.467). This is considered a moderate effect size (Cohen, 1988). Effect sizes for both math anxiety and math performance are shown in Figure 2 and 3 respectively.

To assess the effectiveness of the interventions on participants' math performance (RQ2), we calculated the mean of 41 effect sizes from 30 studies, including a total sample size of 6,097 participants. We found a significant mean standardized effect size of g = 0.502, indicating a moderate effect. The results from these moderator analyses are presented below. Table 1 presents subgroup analyses of math anxiety interventions, and Table 2 covers subgroup-analyses for intervention effects on math performance.

Figure 2

Forest Plot of Math Anxiety Interventions on Math Anxiety – Standardized Mean Difference Between Treatment and Control Group

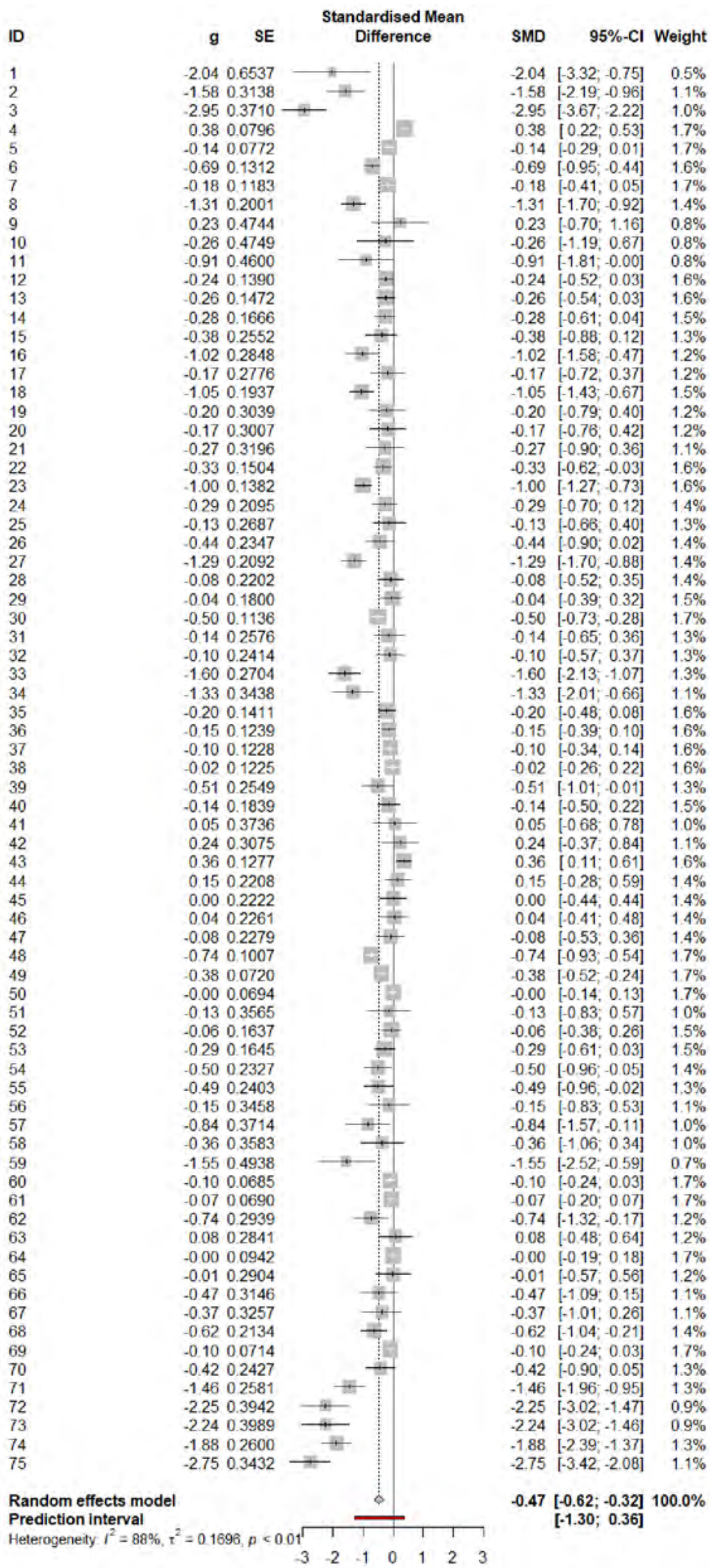


Figure 3

Forest Plot of Math Anxiety Interventions on Math Performance – Standardized Mean Difference Between Treatment and Control Group

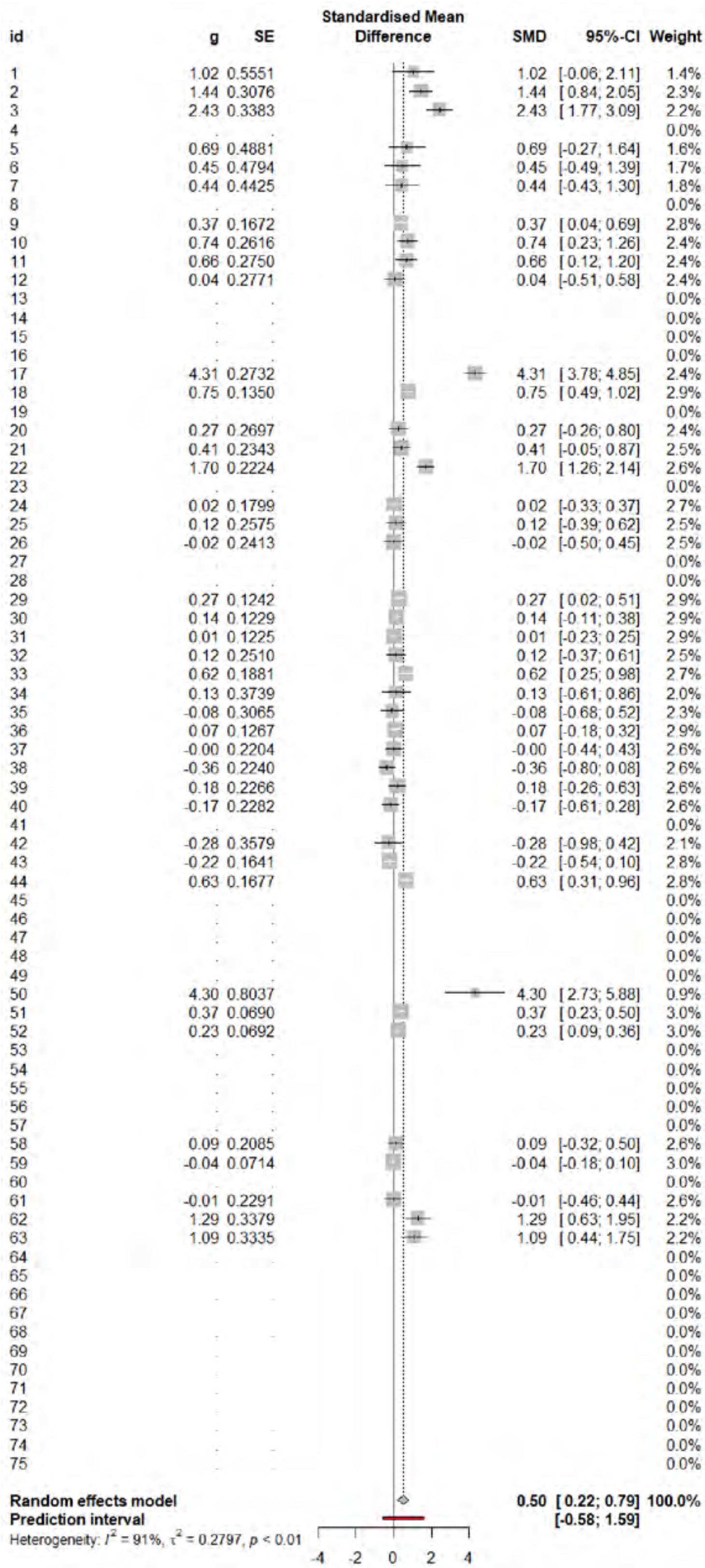


Table 1

Subgroup-Analyses MA Intervention

			95% CI			Between group statistics	
Subcategory	***k***	**SMD**	***LL***	***UL***	t^2	**Q**	***p***
Mean SMD[a]	75	-0.467	-0.616	-0.318	0.170		
Age						10.35	.001
Child ≤ 12 year	26	-0.218	-0.373	-0.063	0.065		
Child > 12 year	49	-0.636	-0.848	-0.423	0.261		
Intervention category						2.34	.311
Motivation	15	-0.251	-0.595	0.094	0.115		
Emotion	36	-0.523	-0.778	-0.268	0.189		
Cognitive support	24	-0.525	-0.732	-0.318	0.162		
Intervention length[b]						8.88	.012
Short	22	-0.207	-0.362	-0.052	0.061		
Medium	16	-0.488	-0.767	-0.209	0.213		
Long	37	-0.617	-0.885	-0.350	0.203		
EPHPP						1.87	.393
Strong	5	-0.512	-1.717	0.694	0.113		
Medium	61	-0.422	-0.581	-0.264	0.169		
Poor	9	-0.713	-1.169	-0.256	0.252		

Note. k = number of effect sizes. SMD = standardized mean difference.
[a]Estimated with a random effects model. [b]Short = intervention completed within 1 day; medium = intervention completed within 3 weeks; long = intervention longer than 3 weeks.

Participant Age

Age was coded into one of two categories: 1) younger than 12, or 2) older than 12. In both age categories, there was a significant effect of intervention on math anxiety, younger than 12 was associated with a small effect size, g = -0.218, 95% CI [-0.373, -0.063], older than 12 was associated with a moderate effect size, g = -0.636, 95% CI [-0.848, -0.423]. Further, the moderation analyses showed that the effects were statistically significantly different from one another (p < .01).

For math performance, results showed a moderate significant effect of intervention on math performance in older students, g = 0.656, 95% CI [0.321, 0.99], but not younger students, g = 0.384, 95% CI [-0.067, 0.835], however the moderation analyses suggested these effects were not statistically significantly different from one another (p = .313).

Intervention Categories

Intervention categories were coded into one of three categories: 1) Motivation, 2) Emotion, and 3) Cognitive support. The Emotion, g = -0.523, 95% CI [-0.778, -0.268], and the Cognitive support category, g = -0.525, 95% CI [-0.732, -0.318], had significant moderate effects on reducing math anxiety while the Motivation category failed to show a significant reduction in math anxiety, g = -0.251, 95% CI [-0.595, 0.094]. However, the moderation analyses suggested these effects were not statistically significantly different from one another (p = .311).

For math performance, results showed a small significant effect of intervention on math performance in the Emotion category, g = 0.368, 95% CI [0.074, 0.662], and a strong significant effect in the Cognitive support category, g = 0.823, 95% CI [0.051, 1.594]. The Motivation category failed to show a significant improvement in math performance, g = 0.2, 95% CI [-0.29, 0.69]. However, the moderation analyses suggested these effects were not statistically significantly different from one another (p = .319).

Table 2

Subgroup-Analyses MP Intervention

			95% CI			Between group statistics	
Subcategory	***k***	**SMD**	***LL***	***UL***	t^2	**Q**	***p***
Mean SMD[a]	41	0.502	0.216	0.787	0.280		
Age						1.020	0.313
Child ≤ 12 year	22	0.384	-0.067	0.835	0.243		
Child > 12 year	19	0.656	0.321	0.990	0.363		
Intervention category						2.28	0.319
Motivation	10	0.200	-0.290	0.690	0.144		
Emotion	19	0.368	0.074	0.662	0.084		
Cognitive support	12	0.823	0.051	1.594	0.882		
Intervention length[b]						1.840	0.399
Short	13	0.240	-0.081	0.561	0.066		
Medium	9	0.750	-0.366	1.867	1.091		
Long	19	0.469	0.156	0.782	0.123		
EPHPP						0.150	0.928
Strong	3	0.696	-1.842	3.235	0.089		
Medium	35	0.468	0.158	0.779	0.332		
Poor	3	0.543	-2.067	3.153	0.679		

Note. k = number of effect sizes. SMD = standardized mean difference.
[a]Estimated with a random effects model. [b]Short = intervention completed within 1 day; medium = intervention completed within 3 weeks; long = intervention longer than 3 weeks.

Intervention Length

Intervention length was coded into one of three categories: 1) Short, 2) Medium, and 3) Long. Interventions denoted as Long, g = -0.617, 95% CI [-0.885, -0.35], and Medium, g = -0.488, 95% CI [-0.767, -0.209], displayed significant moderate effects on reducing math anxiety, while Short interventions, g = -0.207, 95% CI [-0.362, -0.052], showed a small significant effect. Further, the moderation analyses showed that the effects were statistically significant from one another (p < .05). The intervention category Long was significantly more effective in reducing math anxiety compared to Short interventions. No significant differences were found between Long and Medium length interventions and Medium and Short interventions.

For math performance, results showed that Long interventions, g = 0.469, 95% CI [0.156, 0.782], had a significant moderate increase, while Medium, g = 0.75, 95% CI [-0.366, 1.867], and Short interventions, g = 0.24, 95% CI [-0.081, 0.561], failed to show a significant improvement in math performance. However, the moderation analyses suggested these effects were not statistically significantly different from one another (p = .399).

Study Quality

Studies were coded into one of three intervention quality categories based on the EPHPP: 1) Strong, 2) Medium, and 3) Poor. The Medium, g = -0.422, 95% CI [-0.581, -0.264], and Poor, g = -0.713, 95% CI [-1.169, -0.256], had significant weak to moderate effects on the overall intervention effectiveness on attempting to reduce math anxiety. The Strong category did not have a significant effect on interventions attempting to reduce math anxiety, g = -0.512, 95% CI [-1.717, 0.694]. It is important to notice that the moderation analysis shows that the categories were not statistically different from one another (p = .393)

Regarding math performance, results showed a moderate effect for Medium category, g = 0.468, 95% CI [0.158, 0.779), while there were no significant effects from the two remaining categories Strong, g = 0.696, 95% CI [-1.842, 3.235], and

Poor, g = 0.543, 95% CI [-2.067, 3.153]. Here too it is important to notice that the moderation analysis suggests that these effects were not significantly different from one another (p = .928).

Publication Bias

The funnel plot presents all included effect sizes (x-axis) with associated standard errors (y-axis, from large to small), which are based on study sample sizes. Thus, larger errors indicate smaller sample sizes. The plot includes a funnel-shape where studies would ideally follow, as well as a vertical line which represents the mean effect size. From the plot for math anxiety, one can read that the included effect sizes were not normally distributed, larger effect sizes seemed to be associated with larger errors (i.e., smaller sample sizes). This was also true for math performance, although the effects weren't as widespread as for math anxiety. Further, effect sizes for math performance were fewer than for math anxiety. Egger's test confirmed the asymmetric distribution for both measures, suggesting bias was present (p_{ma} < .001, p_{mp} = .029).

The bias might have been derived from only including peer-reviewed and published studies in our meta-analysis. While including both published and unpublished studies in a meta-analysis is sometimes recommended (Light, 1987), it is also acknowledged that the results may be skewed due to potential inaccuracies (Sacks et al., 1987). In this study, we chose to exclude unpublished studies to ensure an accurate and replicable search process, which can be challenging for unpublished studies. See Figure 4 and Figure 5.

Figure 4

Funnel Plot – Math Anxiety Interventions

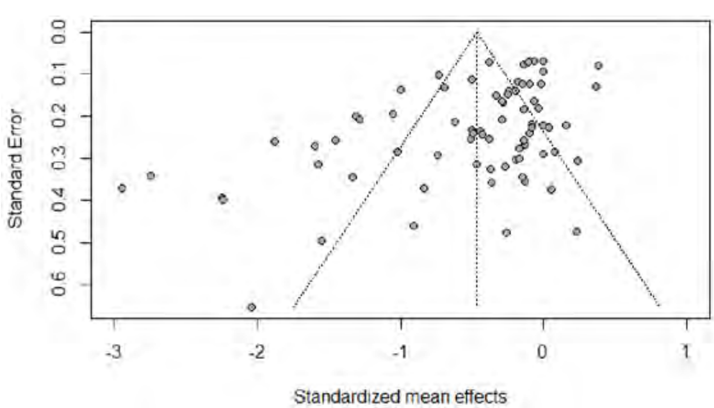
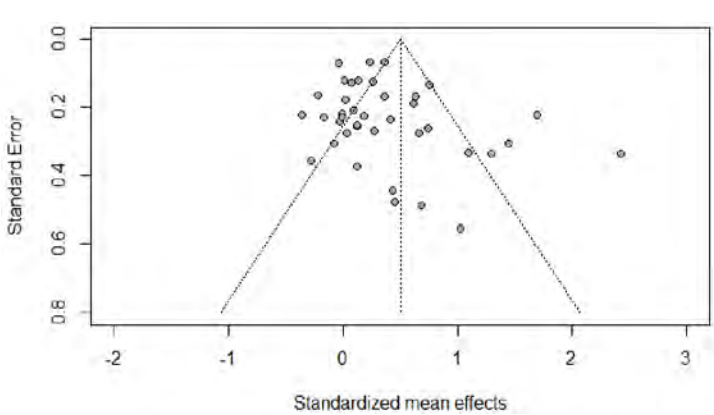


Figure 5

Funnel Plot – Math Performance



Due to an extensive amount of between-study heterogeneity, we choose to not apply the trim-and-fill method, a tool to statistically correct for publication bias, as it could underestimate the effect (Peters et al., 2007).

Discussion

The present meta-analysis examined the effect of math anxiety interventions on both math anxiety and math performance. On average, moderate effect sizes were observed for reducing math anxiety and improving math performance. Interventions that focused on Cognitive support or regulating Emotions were effective in reducing math anxiety and improving math performance. In addition, longer interventions and those targeting students older than 12 had the largest decrease in math anxiety. Study quality was not related to intervention outcomes.

There was no significant difference in the overall effect of age group on math performance, despite the fact that we found descriptive differences in the intervention effect on participants of different ages. This implies that interventions had an effect on participants older than 12 but no effect on participants younger than 12, although the differences between these effects were not statistically significant. In previous research, it has been established that math anxiety increases with age, this might be due to increased awareness of social comparison and the increasing difficulty of mathematics in higher grades (Dowker et al., 2016). Thus, higher levels of math anxiety in older students compared to younger students might be a plausible explanation for the larger effects of interventions on older participants (Ashcraft & Moore, 2009). We found that not all three intervention categories had an effect on math anxiety and math performance. According to the *deficit theory*, high math anxiety levels are primary caused by poor math skills (Sorvo et al., 2019) Our findings support this theory as interventions assigned to the Cognitive support category were effective in reducing math anxiety. These interventions aimed to enhance participants' math skills, through different methods (e.g., study skill and number sense training), with math training as the denominator. These findings align with theories that suggest that cognitive skills support the development of mathematical skills (Decker & Roberts, 2015). Furthermore, it's recommended that math interventions should always provide cognitive support that reduces cognitive load by providing different kinds of instructions that support math learning, including problem-solving skills, knowledge representations, working memory, and executive functioning (Kroeger et al., 2012). Still, many strategies designed to reduce math anxiety only tackle emotions and lack components to train math (Maloney & Beilock, 2012).

The interventions assigned to the Emotion category also resulted in reduced math anxiety. These interventions encouraged participants to adopt a more positive attitude toward math by implementing methods that help them to handle their feelings and levels of math anxiety. These results are in line with the review by Ramirez et al. (2018) who also found that reappraisal and expressive writing are efficient methods in reducing math anxiety. The *debilitating anxiety theory* suggests that math anxiety has a negative effect on math performance (Carey et al., 2016), and it seems likely that the underlying assumption among the interventions in the Emotion category is that poor math achievement is the product of high levels of math anxiety that needs to be adjusted. When examining the development of anxiety, it's important to consider how experiencing failure in a learning context can lead to an increase in anxiety levels (Pekrun, 2006). Furthermore, it's essential to understand the adverse effects of math anxiety on other emotions that are significant while doing math, such as enjoyment in math, self-confidence, and the feeling of being useful, which are essential components in attaining mastery and competence (Ashcraft & Moore, 2009).

The participants in the Motivation category were exposed to exercises aimed at boosting their motivation, but these interventions did not significantly reduce math anxiety. Studies that were assigned to the Motivation category consisted of interventions that allowed the participants to set goals for their math achievement, and to create an environment that encouraged them to reflect on and improve their math skills. These motivational processes are also supported by Luttenberger et al. (2018), who found that self-view, focusing on previous successes and adaptation of achievement goals are effective for learning and reducing math anxiety. Although the reciprocal relationship between motivational constructs and achievement are well documented (e.g., Marsh et al., 2006) it might be that these effects represent more long-term relations and were therefore not found in intervention studies that examined short-term development. For example, both the Expectancy-Value theory and the Self-Determination theory are mainly used to describe and understand long-term relations between motivational constructs and academic achievement. Indeed, Eccles and Wigfield

(2020) conclude that most of what we know about change over time in children's motivational constructs come from studies in several countries of age differences in their mean level. Both the Cognitive support and Emotion interventions are more directly related to the theories aimed to explain the anxiety – performance link while the interventions in the Motivation category are more indirectly related to at least anxiety. However, we recognize that the reliability of this result may be flawed by insufficient power to detect a significant result, as we only found 15 effect sizes for this category in contrast the 40 and 24 effect sizes for the other categories. Taken together we found support for all three theoretical accounts aimed at explaining the math anxiety – performance link. Nevertheless, as both the Cognitive support and Emotion interventions were found to be effective the reciprocal theory appears be the most plausible explanation. This is in line with the Namkung et al. (2019) meta-analysis where they found support for reciprocal relations between math anxiety and performance across 131 studies. Future intervention studies that explicitly test these theories are needed.

Intervention length did moderate the effect on math anxiety, longer interventions had a larger effect on math anxiety than shorter ones, although Short, Medium, and Long interventions were all effective. Previous research has suggested that longer interventions are more desirable in the context of enhancing math performance, although shorter interventions can be just as efficient (DeFouw et al., 2021). The results from our meta-analysis are in line with the assumption that longer interventions are more efficient, possibly due to the duration and the number of sessions that a longer intervention can entail. However, regarding math performance, intervention length did not moderate the results.

We examined how intervention quality was related to intervention outcomes, and according to our moderation analysis, intervention effects did not differ from each other significantly depending on EPHPP-ratings. On a strictly descriptive level higher EPHPP-ratings were associated with non-significant intervention outcomes, whereas interventions with lower EPHPP-ratings were related to significant outcomes. However, as 1) the main effect was not significant, and 2) the distribution of interventions associated with each rating is grossly uneven, it is not meaningful to read into potential nuances between the ratings. Future intervention studies aimed at reducing math anxiety should prioritize using high-quality research designs as the methodological quality of many studies included in our meta-analysis was generally low. Many studies did not report important information such as withdrawals, dropouts, participant information, and the exposure status of participants and assessors. A high-quality study should provide detailed information about data collection methods and address potential issues that could affect the research project. These factors are crucial for ensuring transparency and improving the overall quality of the study.

Limitations

Fifty studies reported math anxiety scores and were analyzed, but only 30 of the 50 studies explored changes in math performance scores. In addition, some studies reported math performance scores using school grades while others used norm-based tests. Moreover, the inclusion criteria of reporting mean scores and standard deviations led to the exclusion of a few studies. The Egger's test and the funnel plot indicated that bias was present. Thornton and Lee (2000) emphasize that all studies should be published, regardless of their outcome. Hence, potentially the present results overestimate the effects of the interventions for the math anxiety part, for the math performance part our data might be considered to suffer from a power-issue. With that said, we argue that this meta-analysis answered the posed research questions and thus provides a substantial contribution to the research community as well as providing a basis for future interventions.

Conclusion

Overall, we found that math anxiety interventions were effective in reducing math anxiety and improving math performance. The results indicated that two of the intervention categories, Emotion, and Cognitive support, were effective in reducing math anxiety and enhancing math performance. In addition, the length of the interventions played an important part regarding the overall effect. Even though shorter interventions can decrease math anxiety, it seems that longer interventions are more effective. We also discovered effects of age, as interventions targeting older students were more effective in reducing math anxiety compared to those aimed at younger students. Therefore, future intervention studies would benefit from being sufficiently long, and give either emotional or cognitive support (or both) in order to reduce math anxiety.

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Supplementary Materials

The Supplementary Materials contain the following items (for access see Index of Supplementary Materials below):

- *Supplementary Document 1:* The supplementary document contains information about the 50 studies that were included in the meta-analysis. Information about each article's sample size, the effect size for math anxiety and math performance, intervention length, study quality rating, and intervention category is presented.
- *Supplementary Document 2:* The supplementary document contains information about how each article was divided into one of three intervention categories: 1) motivation, 2) emotion, and 3) cognitive support. Every intervention is also described briefly.

Index of Supplementary Materials

Sammallahti, E., Finell, J., Jonsson, B., & Korhonen, J. (2023). *Supplementary materials to "A meta-analysis of math anxiety interventions"* [Additional information]. PsychOpen GOLD. https://doi.org/10.23668/psycharchives.12956

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Note. Asterisk (*) indicates all studies (*n* = 50*) included in our meta-analysis.

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