The Effect of Mathematics Anxiety Interventions on Mathematics Achievement: A Meta-Analysis

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Mathematics anxiety is detrimental to student achievement in math. This study uses a meta-analysis to investigate the effectiveness of various mathematics anxiety interventions on improving mathematics achievement of college students. We include intervention studies on college math classrooms with quantitative measures of both mathematics anxiety and achievement. Only RCTs and QEDs written in English are included. We use ERIC as a database. 8 studies were included in the extraction involving 800 participants. Studies generally indicated a moderately positive effect of math anxiety interventions on math achievement (p = 0.00124).

Keywords: mathematics anxiety, classroom interventions, meta-analysis

Mathematics anxiety is common, normalized, and has the potential to sharply change the career trajectory of those who have it. Mathematics anxiety is the feeling of tension or fear provoked by math, mathematical problems, or mathematical situations (Ashcraft & Moore, 2009; Jiang et al, 2021). Individuals with math anxiety suffer from physiological tension and discomfort under mathematical situations (Ashcraft & Krause, 2007; Ramirez et al, 2013). As a result, they display avoidant behavior both in the short term and long term, sacrificing accuracy to rush through math tests, and avoiding math-heavy courses, college majors, and even career paths (Alkhateeb, 2002; Ramirez et al, 2013; Ashcraft & Krause, 2007). Neurological research shows that even brief exposure to mathematical symbols triggers a neural response associated with threat avoidance (Weed et al, 2021).

Students often make pivotal career decisions during college, taking different classes or trying different majors before deciding where to take their career. This gives a unique significance to math anxiety for college students. On the one hand, a negative experience in an introductory math course may turn students away from STEM careers or careers involving math. On the other hand, a positive experience with a math anxiety intervention may convince a student to stick with a STEM career choice. The purpose of this meta-analysis is to investigate the degree to which mathematics anxiety interventions improve the mathematics achievement of college students.

Literature Review

Theoretical Perspective: Mathematics Anxiety and Mathematics Achievement

Literature repeatedly demonstrates a negative correlation between math anxiety and math achievement (Ashcraft & Krause, 2007; Ashcraft & Moore, 2009; Samuel & Warner, 2021). There are three main theories on the cause of this relationship (Codding, 2023). *Cognitive interference theory* suggests that high math anxiety induces excessive cognitive load on the student, taking up working memory and therefore lowering their capacity for reasoning through mathematical tasks (Ashcraft & Krause, 2007; Ashcraft & Moore 2009; Ramirez et al, 2013). *Deficit theory* suggests that the relationship is instead caused by a perceived achievement deficit (Carey et al., 2016; Gunderson et al., 2018; Wang et al., 2015). Under this model, the student performs below her own expectations on some mathematical task, and begins perceiving herself as mathematically incompetent. The student then develops negative feelings around

mathematical activities. The final theory suggests that the relationship is *bidirectional*, with math anxiety detracting from a student's math performance, and subpar achievement causing further anxiety for the student.

Present Study

Interventions on Mathematics Anxiety

Given the three theories above on the relationship between math anxiety and math achievement, interventions aiming to mitigate the effect of math anxiety on student achievement in math can either target math anxiety or math achievement (Codding, 2023). Interventions that target anxiety (behavioral interventions) include affirmations, breathing exercises, stretching, music, and any non-content related activity that can help relax the student's nerves. Interventions that target math achievement (knowledge interventions) include instructional strategies, study strategies, and other interventions that help students break down and understand the content more effectively. By observing how these two types of interventions affect math anxiety, we can contribute more evidence to discern the relationship between math anxiety and achievement.

Research Questions

Q1: How do mathematics anxiety classroom interventions affect mathematics achievement in college students?

Q2: Do combined type interventions affect mathematics achievement differently from behavioral interventions?

Methods

Eligibility Criteria

We use the PICOS framework to define eligibility criteria for this study. The *population* for included studies is college or university students. We choose this population because of their closeness to decision-making moments in their careers. For *interventions*, we choose studies with classroom math anxiety interventions. "Classroom interventions" refers to interventions associated with a course, like beginning lectures with affirmations, incorporating writing exercises in homework, or using group work as part of the class structure. These were chosen because they can be flexibly and cleanly applied by instructors. To accept an intervention as a "math anxiety" intervention, we just check that the authors refer to it as such. For *comparison*, we require a control group that did not receive the intervention by the time the post-intervention measure is taken. For *outcomes*, we check if the study includes quantitative measures for both math achievement and math anxiety. For *study design*, we check that studies are intervention studies with Randomized Control Trials or Quasi-Experimental Design to maintain a baseline for quality. We did not limit the publication date or location of the study, but we did require that studies be written in English.

Database search

We searched ERIC for studies of interventions on math anxiety in college or university math classrooms. We limited the number of screened studies to only the first 150 studies (out of a total 283 found) in the ERIC search results. These included published studies as well as dissertations. With additional time, we would have searched ProQuest for more gray literature to further minimize publication bias. The following search string yielded the results:

(university OR college) AND (mathematics OR math) AND anxiety AND (intervention OR program OR strategy$ OR treatment$) AND ((classroom$ OR school$ OR education$) OR (pedagogy$ OR teaching$)) AND (achievement$ OR performance$ OR test score$ OR outcome$)

The studies were moved to Zotero, where an initial PDF search was conducted. Next, they were moved to Rayyan (https://www.rayyan.ai/) to begin screening.

Screening

The screening was done in two stages. First, 150 studies were taken through title and abstract screening. At this stage, the first author checked the language, population, intervention, and outcomes. 103 studies were excluded, and 47 studies passed to full text screening. For this stage, the first author checked the study design and inclusion of a control group in addition to the rest of the criteria. Only 8 studies passed this screening into extraction (denoted with a * in the citations).

Extraction

We extracted descriptive information on studies (title, authors, and publication year), effect size information (means, group size, and standard deviations on the quantitative achievement measure for each treatment and control group). We also coded the type of treatment (behavioral, math knowledge, or combined), and who delivered the intervention (researcher, teacher, computer, or other) for use in the moderator analysis. A nested structure was used for effect sizes. For example, suppose a study included two treatment groups and a control group, and then measured the effect with three exams. Then the two treatment groups would be coded as "group 1" and "group 2," and each would have an effect size for "outcome 1," "outcome 2," and "outcome 3," and all of these would fall under a single "study ID".

Analysis and Results

Effect Size Analysis

The interventions in these studies vary in type, delivery, date, and location, so there are factors other than sampling error affecting extracted effect sizes. We use a random effects model to account for that in the meta-analysis. We use Cohen's d analysis with the Hedges' g correction to analyze pooled effect sizes. A multivariate model is used for the entire analysis since some studies include multiple treatment groups or multiple achievement measures, causing dependencies between the effect sizes.

We use the metafor package in R with the robust standard error correction from clubSandwich to compute the result. This produced a pooled effect size of 0.373 with a standard error of 0.076 ($p = 0.00124$, $df = 12$). The extracted studies therefore show a significant, moderate effect of the interventions on student math achievement. The heterogeneity test shows significant heterogeneity in the sample, affirming the choice of the random effects model.

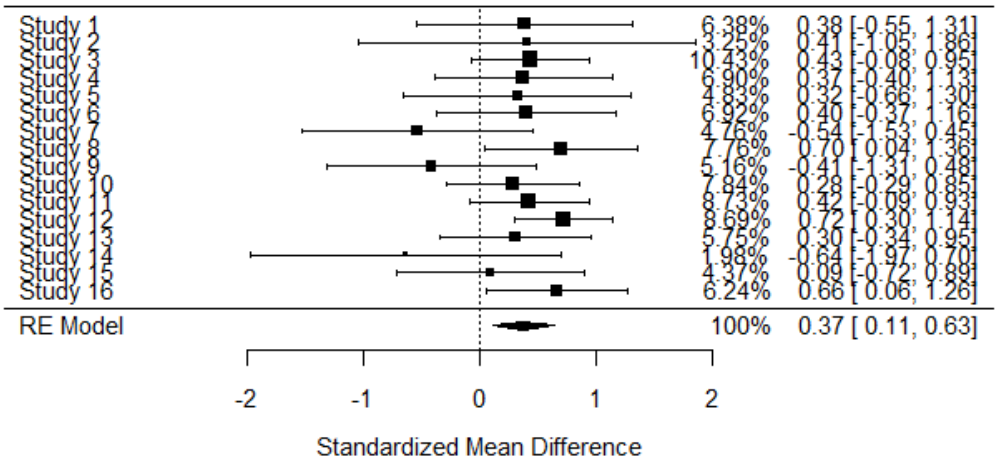

Figure 1. Forest plot of the means in the meta-analysis.

Moderator Analysis

The moderator analysis is performed through a meta-regression. There was not enough data to analyze effectiveness on mathematics anxiety or who delivers the intervention as moderators, but treatment type was analyzed. The test of moderators showed that treatment type was indeed a moderator in this study ($p < 0.05$). In particular, while "behavioral only" and "combined type" interventions both had moderate positive results on student achievement, the effect was only found to be statistically significant for the combined type. There were not enough "math knowledge only" interventions for that effect to be analyzed. This is likely due to the eligibility criterion requiring the interventions to be math anxiety interventions.

Table 2. Descriptive results of meta-regression.

Treatment Type	Effect Size	SE	Z-Val	P-Val
Behavioral only	0.3483	0.2083	1.6718	0.0946
Combined	0.3814	0.1765	2.1603	0.0307
Regression coefficients	$\boldsymbol{\sigma}_1$	$\boldsymbol{\sigma}_2$		
	< 0.0001	0.0863		

Descriptive Results

The studies analyzed were published between 1982 and 2020, with a total of 800 participants. These studies were generally set in a university course, with an intervention applied throughout a semester. Post-intervention results are taken after the end of the course. All studies found a significant effect of the intervention on mathematics anxiety. Of the 16 effect sizes, 10 were based on a combined treatment type and 6 were based on a behavioral-only intervention. Studies generally found math anxiety interventions to have a positive effect on math achievement.

Answers to Research Questions

Q1:How do mathematics anxiety classroom interventions affect mathematics achievement in college students?

A: Mathematics anxiety classroom interventions have a moderately positive effect on mathematics achievement for college math students.

Q2: Do combined type interventions affect mathematics achievement differently from behavioral interventions?

A: Treatment type does moderate the effect of math anxiety interventions on math achievement. In particular, combined math-knowledge + behavioral interventions have a more significant positive effect on mathematics achievement than behavioral-only interventions.

Discussion and Implications

The results of the meta-analysis demonstrate that classroom math anxiety interventions have a moderately positive effect on math achievement, with the result for combined behavioral + math knowledge interventions being more significant than behavioral-only interventions. Therefore, we can recommend that college math instructors implement combined-type interventions to break the hold math anxiety has over their students. This paper suggests that even students taking their one required math course in college can improve their math performance and be relieved from their math anxiety through a classroom intervention. Students impacted by math anxiety can be better prepared to choose and succeed in STEM majors and math-heavy career paths (Ashcraft & Krause, 2007; Ramirez et al, 2013).

There are some important limitations for this study. First, the screening and extraction was done by one person only, so mistakes are inevitable. The three stages of screening help mitigate this problem, and the first author reviewed decisions for each stage of screening and the extraction. However, two more papers had to be excluded during extraction due to full-text screening errors. It is possible there are more mistakes that were not caught. Second, with so few studies, most of which come from published journals, there is a plausible potential for publication bias. Publication bias is the phenomenon where studies are more likely to get published if they find statistically significant results, especially small studies or studies with lower power (Palmer et al, 2008). This can bias the results of a meta-analysis to produce a higher effect size.

The final major limitation is the number of studies included. The goal of the moderator analysis was to provide additional data to inform the theories on the relationship between math anxiety and math achievement. While a more statistically significant effect was observed for combined treatment than behavioral-only treatments, the effect sizes themselves were close (0.34 vs 0.38). It is possible that behavioral-only interventions simply have a wider confidence interval (larger standard deviation) and would show significance with a larger sample. A significant effect of behavioral-only interventions on math achievement would corroborate interference theory, as targeting math anxiety without math knowledge improves expressed knowledge (Ashcraft & Krause, 2007; Ashcraft & Moore 2009; Ramirez et al, 2013). Moreover, no math knowledge-only studies were included, and this was because of the eligibility criterion requiring math anxiety interventions. Expanding the pool of studies may resolve this, but it may be more effective to instead search interventions more generally, and code the treatment type on all of them (with the same behavioral, math knowledge, and combined types as codes).

Overall, while the results of this study are promising, a study amending the above limitations would be well-positioned to give better recommendations on types of interventions a college instructor might try with her students as well as a deeper understanding of the relationship between math anxiety and math achievement.

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