Distraction in Math Anxious Individuals During Math Effort-Based Problem Solving

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Abstract

Math anxiety is a pervasive issue in higher education that is often associated with poor performance outcomes. A hypothesized reason for this association is that individuals with math anxiety experience negative and intrusive thoughts related to the situation, their performance, and its consequences. These distractions are thought to be specific to math-related contexts. However, recent empirical evidence from the test anxiety literature calls the anxiety-distraction association into question. Here, we demonstrate that (a) math anxiety is associated with higher average reports of negative distraction, (b) that math anxiety-induced distraction is specific to the math problem-solving domain, and (c) that test anxiety also accounts for higher ratings of math-specific negative distraction. Investigating potential mechanisms underlying the math anxiety–poor math performance relationship is necessary for implementing effective interventions that foster math success, both in educational settings and in everyday life.

Keywords: math anxiety; distraction; math performance; decision-making

Introduction

Disruptive thoughts while performing in high-stakes academic settings may be an all-too-familiar experience for many students. Perhaps they sit down to take an exam, flip open the packet, skim the instructions, and begin to work on the problems. As they are solving the problems, they begin to have anxious, intrusive thoughts while completing the problems: “I’m worried about how I’m doing on these problems,” “I must be doing so poorly, what if I fail?” or “Can this please be over already?” Perhaps their palms begin to sweat, their heart begins to pound, they feel as though they cannot remember what they studied, or they cannot even focus on the problems in front of them. Their head is consumed by these negative thoughts to the detriment of their performance.

Math anxiety, characterized by negative emotions and tension toward mathematics, poses a widespread challenge in the field of education (Ashcraft, 2002; Choe et al., 2019; Richardson & Suinn, 1972). Math anxiety is related to students’ perceptions of math ability and expectations about their performance (Meece, Wigfield, & Eccles, 1990). Physiological research has shown that elevated cognitive and physiological reactivity (e.g., heart rate changes) might underlie these negative attitudes and perceptions about math (Faust, 1992; Suárez-Pellicioni, Núñez-Peña, & Colomé, 2016). Furthermore, math anxiety and math-related attitudes can influence personal decisions, such as study strategies, the pursuit of advanced coursework, and choice of college major (Ashcraft, 2002; Hembree, 1990; Jenifer et al., 2022).

One prominent hypothesis proposed is that math anxiety interferes with math problem-solving, and in turn influences performance outcomes in math-specific contexts. The distraction hypothesis suggests that math anxiety consumes working memory resources that would otherwise be available for problem solving and skill execution, and/or biases attentional resources to perceive math-related information as emotionally salient and threat-related. That is, some cognitive resources are redirected toward distractions related to the current situation, including negative thoughts about performance and about the situation itself (Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Beilock & DeCaro, 2007; Beilock et al., 2004; Suárez-Pellicioni et al., 2015).

It is believed that math anxiety—though correlated with other, more generalizable anxiety constructs like trait and test anxiety—is separable, even if the extent of this separability is debated. Despite this debate, many researchers concur that theories stemming from the generalized testing anxiety construct can be used to inform research on math-specific anxiety (Hembree, 1990). One hypothesis, known as the distraction hypothesis, has been examined across various high-stakes and anxiety-inducing contexts, including general testing and math-specific scenarios. Research on cognitive performance anxiety (e.g., test anxiety; Eysenck et al., 2007; Mandler & Sarason, 1952; Wine, 1971) suggests that mental processes may be disrupted by intrusive thoughts and worries that interfere with task performance. Anxiety has been hypothesized to disrupt task-related competition for working memory resources (Eysenck & Calvo, 1992), interfere with the retrieval of learned information (Ashcraft & Kirk, 2001; Beilock & Carr, 2005), and hinder goal-directed attention control that in turn creates vulnerabilities to bottom-up distractions (Eysenck et al., 2007). Therefore, anxieties like math and test anxiety are believed to inhibit performance, even when factors like prior knowledge and competency are

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accounted for (Ashcraft, 2002; Hembree, 1988; 1990; c.f. Theobald, Breitwieser, & Brod, 2022).

One recent study investigating the effect of test anxiety on exam performance did not support the hypothesis of anxiety-induced distraction in task processing and knowledge retrieval. Theobald and colleagues (2022) examined whether test anxiety predicted performance in a high-stakes medical school exam when prior knowledge (assessed before the exam) was controlled for, suggesting that a) test anxiety did not predict a performance drop from mock exams to the final exam, and that b) test anxiety did not predict exam performance, even when mock exam performance and non-evaluative preparatory knowledge were accounted for. These results question the notion that distraction is the sole explanation for why anxious students perform worse. However, the study by Theobald et al. (2022) was specific to test anxiety and to an exam context, and there was not a measure of distraction included.

Here, we evaluate the math-specific distraction theory via thought probes. We investigate whether math anxiety predicts negative distraction, and whether distraction is specific to math contexts. We expect that distraction should be evident during our effort-based decision-making task, as choosing the incorrect response to problems on the task results in missing out on a higher performance-based monetary award. We hypothesize that math anxiety will be associated with math-specific negative thoughts about performance and the situation, consisting of worries about one's own capabilities and fears about task consequences. If this hypothesis is supported, math anxiety will predict higher ratings of self-reported worries during performance on the math problems, but not the word problems. Alternatively, if we observe that math anxiety, among other anxiety predictors, is not significantly predictive of self-reported distraction during performance on the math problems, this finding would be in line with Theobald and colleagues (2022). That is, our study's findings would provide another scenario in which the distraction hypothesis is undermined.

Materials and Method

The Present Study

The findings of the present study are part of a larger study in which we assessed both the cognitive mechanism of math-specific distraction and the behavioral mechanism of effort avoidance during problem solving using an effort-based decision-making task. Results pertaining to the mechanism of effort avoidance are to be reported elsewhere. Here, we report all procedures, measures, and criteria for data inclusion and exclusion. The preregistration for our study can be accessed on Open Science Framework (https://osf.io/7as8t/).

Participants

This study was approved by the Case Western Reserve University Institutional Review Board (IRB no. STUDY20221163). Participants completed the study online via Prolific and were required to provide informed consent before participating. Participants were self-identified as between the ages of 18 to 35, fluent in English, and currently residing in the United States. Participants were compensated a base rate of $8.00 plus a task performance bonus of up to $5.40 (total: *M* = $11.57, *SD* = $0.45).

We expected the first four blocks of our effort-based decision-making task (the Choose-and-Solve Task) to be a near replication of Choe et al.'s Study 1 results, thus anticipating a similar effect size. Choe et al. (2019) found a correlation of $r = -.30$ between math anxiety and hard choice probability (the operationalization of the inverse of avoidance behavior, results to be reported elsewhere). A desired sample size of 112 was set to detect an expected correlation of –.30 with 90% power at a significance level of .05, after planning to exclude about 15% of participants who did not meet our preregistered easy problem-solving accuracy rate (see exclusion criteria at https://osf.io/7as8t/). One hundred thirty participants completed the study. Seven participants were excluded from analyses for having average accuracy rates on the easy problems below 70% across the 7 blocks of the task. We report the results of 123 participants (age: *M* = 27.73, *SD* = 4.49; gender: 56 females, 59 males, and 8 other identities/prefer not to answer).

Questionnaires and Predictor Variables

Pre-Task Math and Reading Anxiety Questionnaires Math anxiety was assessed using the shortened version of the Mathematics Anxiety Rating Scale (sMARS; Alexander & Martray, 1989). Participants rated the degree of anxiety they would experience in different math-related scenarios (e.g., "walking to math class," "being given a 'pop' quiz in a math class") along a 5-point Likert scale from 1 = not at all to 5 = very much. Math anxiety was calculated as an average of the 25 items ($\alpha = 0.97$), with a higher average indicating a greater level of math anxiety.

To separate math-specific anxiety from anxiety associated with the non-math (word) contexts, we also administered a 25-item Reading Anxiety Rating Scale (sRARS; Choe et al., 2019). Participants rated the degree of anxiety they would experience in various English-related scenarios (e.g., "walking to English class," "being given a 'pop' quiz in an English class") along a 5-point Likert scale from 1 = not at all to 5 = very much. Reading anxiety was calculated as an average of the 25 items ($\alpha = 0.97$), with a higher average indicating a greater level of reading anxiety.

Pre-Task Questionnaires on Anxiety Covariates We administered questionnaires for trait anxiety, test anxiety, and social desirability to control for potential anxiety covariates. Trait anxiety was measured using the 20-item trait subsection of the State-Trait Anxiety Inventory (Spielberger, 1983), where participants rated their degree of agreement with statements about their tendencies to feel anxious and/or content (e.g., "I get in a state of tension or turmoil as I think over my recent concerns and interests" and "I am 'calm, cool, and collected'"). Test anxiety was measured using the Test Anxiety Inventory (Spielberger, 1980), where participants rated their degree of anxiety they would experience across 20 testing-related prompts (e.g., “While taking examinations I have an uneasy, upset feeling” and “I feel confident and relaxed while taking tests”). Items from both questionnaires were scored on a 4-point scale from 1 = not at all to 4 = very much so and were reverse-coded when appropriate. Trait and test anxiety were each calculated as a summed score between 20 to 80 points (trait anxiety: $\alpha = 0.95$, test anxiety: $\alpha = 0.97$), with higher sums indicating greater levels of trait and/or testing anxiety. Finally, we administered the 33-item Marlowe-Crowne Social Desirability Scale (Crowne & Marlowe, 1960) to capture the potential underreporting of anxiety (Weinberger et al., 1979) and to gauge participants’ inclination to provide socially desirable responses ($\alpha = 0.87$).

Task Domain and Performance-Based Predictors In addition to problem domain (math or word) serving as a model predictor, predictor variables performance on the effort-based problem-solving task were collected, including math/word competency, easy math/word accuracy, hard math/word accuracy, easy math/word response times, and hard math/word response times.

Math and word problems that were presented to participants were sorted into 7 levels of difficulty. Easy problems were all drawn from the lowest difficulty level, and hard problems were drawn from Levels 2-7. The average level of hard problem difficulty, obtained for math and for word trials, served as an operationalization of an individual’s math and word competency.

Easy problems drawn from the lowest difficulty level were designed for 90% or greater accuracy. We calibrated the difficulty of hard problems to a target accuracy level of 70% by implementing a 2-up-1-down staircase procedure (Choe et al., 2019), where the level of difficulty increased after two successive correct trials and decreased after one incorrect trial (with the minimum level of 2).

Post-Task Demographic Predictors Following completion of the effort-based decision-making task, participants filled out a series of post-task questions, including demographic information. Demographic variables, including gender, age, highest level of education (using American standards; e.g., high school/GED, some college, Bachelor’s degree, advanced degree), highest level of math education (using American standards; e.g., algebra, geometry, trigonometry, calculus), and income served as predictors.

An Effort-Based Decision-Making Task: The Choose-and-Solve Task

The Choose-and-Solve Task is an effort-based decision-making task developed by Choe et al. (2019) for online data collection using jsPsych (de Leeuw, 2014). The task includes math and word trials that each have a “choose,” a “solve,” and a “feedback” phase. The “choose” phase presents participants with two cards: an easy card always worth a 2-cent reward, and a hard card offering varying rewards of either 2, 3, 4, 5, or 6 cents (see panel A in Figure 1). The domain (math or word) of the easy and hard cards was kept the same within a given trial. The “solve” phase presented participants with a math or word problem drawn from a large pool (1999 math problems and 1858 word problems; see panel B in Figure 1). A math trial presented participants with a multidigit multiplication problem with a blank to fill, while a word trial presented a fill-in-the-blank spelling problem. Participants were given 3 options to select from to fill in the blank. In the “feedback” phase, participants received accuracy and reward feedback, and for correct problems, received points that directly converted into a financial bonus (see panel C in Figure 1). Points were not deducted for incorrect responses.

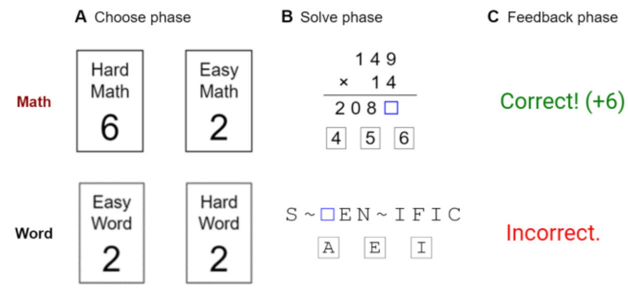

Figure 1: Choose-and-Solve Task layout.

The Choose-and-Solve consists of three practice blocks, and seven main blocks with 20 trials each (10 math and 10 word). Problem domain (math or word) and difficulty (easy or hard) were counterbalanced within each block. At present, we report analyses from the first four blocks of the task, as the final three blocks test a separate hypothesis (results to be reported elsewhere).

Dependent Variable: Negative Distraction Probes

To measure the types and frequency of distractors elicited within the context of a math and non-math problem-solving task, we created a modified version of DeCaro and colleagues’ (2010) retrospective report. Participants were prompted between blocks of the problem-solving task to report the degree to which they agreed with experiencing seven different categories of task-related or unrelated thoughts in the previous block of trials (“Consider your thoughts while performing the MATH/WORD problems during the previous section of the task. Please indicate the frequency of each of your thoughts based on the statements below”). We measured positive task-related distraction, negative task-related distraction, and task-unrelated distraction by prompting participants to consider their thoughts while performing problems during the previous block of the task, and to rate the frequency of each category of thoughts on a scale ranging from 0 to 3 (0, never; 1, rarely; 2, sometimes; 3, often). Participants responded to thought probes for both the frequency of their thoughts related to solving the math problems, and for solving the word problems. To determine the degree of negative distraction related to each participant’s perception of their performance and the situation, we calculated the ratings of distraction from probes 3 (“Negative thoughts about my performance”), 4 (“Anxiety about my performance”), and 6 (“General negative thoughts related to the situation or the task") for both the math and the word problems of each block of the task. These distraction ratings for the math and word conditions served as our dependent variable of interest.

Statistical Analysis, Missing Values, and Data Non-normality

Statistical tests were performed using Python 3.9.13 and 3.12.2, and JASP Versions 0.17.3 and 0.18.3. The statsmodels.formula package was used to perform tests in Python, and the mixedlm function was used to perform linear mixed-effect model analyses with random effects in Python. JASP was used to conduct Spearman's correlations. Independent and dependent variables were standardized for linear mixed-effect analyses. Predictor and outcome variables were standardized.

Due to the small number of participants (*N* = 8) in gender categories other than male or female, participants in other gender categories (including choosing not to disclose) were coded as a third gender category—Other Gender—in the linear mixed-effect model. The effects of this category are removed from Figure 2 as the wide error bars with this small sample disturbed scaling for the other variables. Highest level of education, highest level of math, and income were coded as integers. Data for participants who selected "prefer not to answer" on any of these predictors (highest level of education: 3 participants; highest level of math: 7 participants; income: 8 participants) were imputed with the mean response on each predictor. We encountered instances where participants had missing accuracy, RT, and/or competency values. This was due to the participants either choosing not to solve any easy math problems or any hard math problems for the duration of the first four blocks of the task (no easy problems chosen: 2 participants; no hard problems chosen: 11 participants). We treated these instances as missing values in their respective categories during analysis.

In the present study, we exclusively report results of tests that are robust to non-normality. Many of our variables exhibited non-normal distributions like those found previously (Choe et al., 2019). Correlational analyses using Spearman's correlations are reported in Table 2.

Results

Assessing Distractor Probe Reliability

Negative distraction probes consisted of three items per block, with internal consistency for the math probes ranging by block from .58 to .75 (Block 1: α = .75; Block 2: α = .58; Block 3: α = .64; Block 4: α = .61). Math negative distraction probes displayed good internal consistency across the task (Blocks 1 through 7; α = .94), and the four blocks used in the present analyses (α = .89). Similar in internal consistency, the word probes ranged by block from .59 to .63 (Block 1: α = .63; Block 2: α = .64; Block 3: α = .61; Block 4: α = .59). Word negative distraction probes displayed comparable internal consistency to that of the math probes across the task (α = .94) and in the first four blocks (α = .89). It is worth noting that for both math and word probes, alpha values display greater levels of internal consistency were the sixth probe to be removed, suggesting greater cohesiveness between negative performance probes (Probes 3 and 4) than the negative situational probe (Probe 6).

Testing the Math-Specific Distraction Hypothesis

We examined the effects of math anxiety—among other anxiety, performance, and demographic measures serving as fixed factors—on negative distraction during the Choose-and-Solve Task (see Figure 2 for detailed results). Descriptives for self-reported questionnaires and behavioral measures are reported in Table 1. Summary statistics and the correlation matrix for math anxiety and distraction ratings by block are reported in Table 2.

To test the relationship between math anxiety and distraction, we conducted a linear mixed-effect model analysis on the first four blocks of the Choose-and-Solve Task. Linear mixed-effect models allow for analyses of one-time measures (e.g., math anxiety) with repeated measures (e.g., math distraction and word distraction), and are robust to non-normally distributed data.

We entered the following as fixed effects in the model: 1) other types of anxiety, including reading anxiety, trait anxiety, test anxiety; 2) problem-solving variables, including math competency, easy and hard math accuracy, and easy and hard math RT; 3) demographic variables, including gender, age, highest level of education, highest level of math, and income; 4) social desirability; and 5) problem domain. Participant ID was added as a random effect. Our dependent variable consisted of negative distraction probes from the math and word conditions between each of the first 4 blocks of the Choose-and-Solve task. Out of 246 rows (123 participants x 2, math and word), 26 rows were dropped because of missing values for problem-solving variables. 220 observations were entered into the model. The maximum likelihood estimation method was used to fit the model. Our overall model accounted for about 60% of the variance in mean distraction ratings (R^2 = .62; see Figure 2 for details)

After controlling for related anxiety variables, the problem-solving domain, and demographic factors, we found that math anxiety significantly predicted higher mean ratings on the negative distraction probes (β = 0.24; 95% CI, 0.03 to 0.44; *p* = .022). This suggests that people with higher levels of math anxiety are more likely to report experiencing negative thoughts related to their performance and the situation while problem solving. Notably, the average adaptive difficulty level of the task was not a significant predictor, suggesting that anxiety-induced distraction is unlikely to simply be a function of level of math knowledge or competency.

In addition to math anxiety, we found a significant main effect of domain on distraction (β = –0.12; 95% CI, –0.23 to –0.008; *p* = .035), indicating that participants were less likely to report distraction during problem solving on average in the word domain than in the math domain. We did not observe a significant interaction effect between math anxiety and domain on distraction. For those with other gender identities, gender predicted lower mean ratings of distraction (β = –0.61; 95% CI, –1.16 to –0.07; p = .027), though we caution against strong interpretations given the small sample size of this category.

We found that—aside from math anxiety, domain, and gender—three other predictors significantly accounted for mean ratings of negative distractibility. We found that the highest level of educational attainment—but not the highest level of math-specific educational attainment—predicted higher mean ratings on the negative distraction probes (β = 0.20; 95% CI, 0.06 to 0.34; p = .005). This suggests that greater educational attainment, regardless of subject matter or field of study, may elicit greater anxieties and concerns about performance and/or the situation. Finally, along with math anxiety, we found that trait anxiety (β = 0.18; 95% CI, 0.009 to 0.35; p = .04) and test anxiety (β = 0.39; 95% CI, 0.20 to 0.58; p < .001) significantly predicted higher mean ratings on the negative distraction probes. Taken together, these results suggest that various forms of anxiety increase distractibility during problem solving, and that distraction is more likely to manifest in the math domain.

Table 1: Descriptive statistics of self-report questionnaires and behavioral measures from the Choose-and-Solve Task.

	Measure	N	M (SD)
Self-reports	1 Math anxiety	123	2.42 (0.83)
	2 Reading anxiety	123	1.96 (0.80)
	3 Trait anxiety	123	47.15 (14.64)
	4 Test anxiety	123	44.70 (16.57)
	5 Social desirability	123	14.09 (6.73)
Choose-and-Solve Task	6 Math competency	112	3.33 (1.08)
	7 Easy math accuracy	121	0.93 (0.10)
	8 Easy math RT (s)	121	2.47 (0.77)
	9 Hard math accuracy	112	0.60 (0.23)
	10 Hard math RT (s)	112	4.00 (1.10)
	11 Word competency	118	3.67 (0.91)
	12 Easy word accuracy	122	0.93 (0.12)
	13 Easy word RT (s)	122	2.28 (0.43)
	14 Hard word accuracy	118	0.67 (0.13)
	15 Hard word RT (s)	118	3.18 (0.69)

Note. Descriptives were based on 123 participants that passed the problem-solving accuracy criteria (see Materials and Method). During choice trials of the Choose-and-Solve Task, participants chose either easy or hard problems to solve in both math and word conditions. Because of this ability to choose, some participants were excluded given that they selected only easy or only hard problems to solve, and therefore lacked either easy or hard measures.

Table 2: Descriptive statistics and correlation matrix of math anxiety and average ratings on math and word distraction probes.

Variable	Math Probes M (SD)	1	2	3	4	5	6	7	Word Probes M (SD)
1 Math anxiety	2.42 (0.83)	—	.46	.46	.54	.47	.54	.55	2.42 (0.83)
2 Block 1 average rating	1.46 (0.83)	.53	—	.76	.72	.66	.88	.81	1.25 (0.75)
3 Block 2 average rating	1.26 (0.73)	.53	.77	—	.78	.69	.90	.86	1.22 (0.76)
4 Block 3 average rating	1.31 (0.80)	.51	.66	.78	—	.79	.92	.90	1.26 (0.75)
5 Block 4 average rating	1.34 (0.69)	.55	.62	.65	.73	—	.86	.87	1.33 (0.74)
6 Block 1-4 average rating	1.34 (0.69)	.60	.87	.90	.90	.84	—	.96	1.27 (0.68)
7 Blocks 1-7 average rating	1.36 (0.68)	.63	.82	.87	.86	.84	.90	—	1.28 (0.66)

Note. Results were based on 123 participants that passed the problem-solving accuracy criteria (see Materials and Method). Math probe descriptives are presented in the second column from the left; word probe descriptives are presented in the rightmost column. Spearman's correlations for the math probes are located below the diagonal; Spearman's correlations for the word probes are located above the diagonal. All correlations are significant at the p < .001 level.

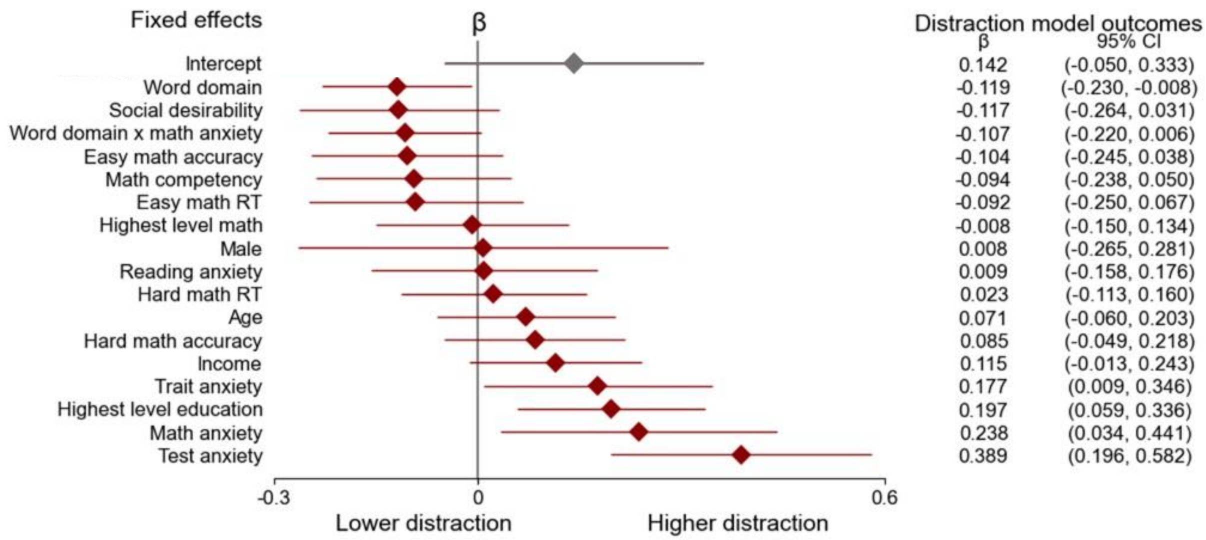

Figure 2: Effects plot of predictors in linear mixed-effect model on average negative distraction. The effects of other gender identities are removed, as the wide error bars with this small sample disturbed scaling for the other variables.

Discussion

Math anxiety has been hypothesized to negatively predict math performance via math-related distraction (Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Beilock et al., 2004). Though math-anxiety-induced distraction has long been hypothesized as a key mechanism of poor math performance, recent evidence against the distraction hypothesis (Theobald et al., 2022) has called into question whether anxiety-related distracting thoughts indeed influence performance outcomes during high-stakes problem-solving scenarios. To determine whether math anxiety indeed predicts math distraction, we modified an effort-based decision-making task (the Choose-and-Solve Task) to include inter-block thought probes that tapped various categories of distracting thoughts experienced during math and non-math problem solving.

We provide evidence in support of performance-related and situational distraction within the context of a math and non-math problem-solving task in which a performance-based monetary bonus was at stake. First, using linear mixed-effect modeling, our results provide evidence further supporting the distraction hypothesis. We found an association between self-reported measures of math anxiety and math distraction, even when controlling for other factors related to knowledge and performance, like accuracy and competency. Furthermore, we found evidence in support of the notion that high levels of distractibility are specific to math problems: we found a significant effect of domain on distractibility, such that participants were more likely to report distractibility in the math domain than the word domain.

Second, although distractibility appeared domain-specific, we also observed that other, more generalized forms of anxiety each contributed to greater ratings of math-specific distraction. Interestingly, though math anxiety was associated with both trait and test anxiety, we found that math and test anxiety were highly correlated ($\rho = 0.74$) like that of previous studies (see Choe et al., 2019; math and trait anxiety $\rho = 0.43$). In addition, we found that test anxiety had a significant effect on ratings of distraction, such that greater test anxiety contributed to greater mean distraction ratings. This finding not only provides evidence of math anxiety's influence on performance- and situation-related distraction, but evidence in favor of testing-anxiety-induced distractibility. This supports the notion of an anxiety-induced distraction hypothesis, but it does raise questions as to the exclusivity of distraction. It may be that math-specific distractibility is induced by math, trait, and/or testing anxiety, and its manifestation may not be exclusive to the present study's Choose-and-Solve Task. Other high-stakes contexts may overlap, such as a math tests or a quantitative portion of an aptitude exam. Future studies should explore potential means of parsing out the effects of different types of anxiety on math and non-math distraction. Furthermore, future studies should explore whether anxiety-induced distraction plays a mediating role on measures of math performance and apply math-specific distraction research to ecologically valid settings like the classroom.

Taken together, our findings further support the distraction hypothesis, and provide evidence that math anxiety elicits distraction specific to math problem-solving. Insights from the present study can be used when developing interventions targeting math-anxiety-induced, math-specific distraction that has traditionally hindered math performance. These interventions may increase achievement and attainment in math-related educational and occupational contexts.

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