AMERICAN PSYCHOLOGICAL ASSOCIATION

Journal of Educational Psychology

ISSN: 0022-0663

2023, Vol. 115, No. 2, 229–240
https://doi.org/10.1037/edu0000759

The Mediating Role of Attention in the Association Between Math Anxiety and Math Performance: An Eye-Tracking Study

Tianyu Li[1], Michaela Quintero[1], Michael Galvan[1], Sierra Shanafelt[1], Leslie M. Hasty[2], Derek P. Spangler[3], Ian M. Lyons[4], Michèle M. M. Mazzocco[5], James R. Brockmole[6], Sara A. Hart[7], and Zhe Wang[1]
[1] Department of Human Development and Family Sciences, Texas Tech University
[2] Department of Psychiatry, Texas Tech University Health Sciences Center
[3] Department of Biobehavioral Health, Pennsylvania State University
[4] Department of Psychology, Georgetown University
[5] Institute of Child Development, University of Minnesota
[6] Department of Psychology, University of Notre Dame
[7] Department of Psychology, Florida State University

OPEN DATA
OPEN MATERIALS

Math anxiety (MA) and math performance are generally negatively correlated (Barroso et al., 2021; Namkung et al., 2019). However, the mechanisms underlying this negative association remain unclear. According to the attentional control theory (ACT; Eysenck et al., 2007), anxious individuals experience impaired attentional control during problem solving, which compromises their performance on cognitive tasks. In a sample of 168 elementary and middle school students, the current study used an eye-tracking approach to investigate whether math-anxious students exhibit deficits in their attentional control during a math problem solving task and whether such attentional control deficits account for the negative association between MA and performance on this math task. Consistent with the ACT, we found that students with higher MA were more likely to engage attention to both task-relevant and task-irrelevant distractors during problem solving, and their enhanced attention to these distractors was associated with their impaired performance on the math task. These findings suggest that the MA-related math performance deficit is partly mediated by impaired attentional control, which is indicated by the maladaptive attentional bias toward distracting information during math problem solving.

Educational Impact and Implications Statement

Students with higher math anxiety often show poorer math performance compared with students with lower math anxiety. One possible explanation for this phenomenon is that students with higher math anxiety are more easily distracted by extraneous information during problem solving. By examining the attention allocation patterns during an arithmetic verification task in a group of elementary and middle school students, our findings support this explanation. We argue that external distracting information may disrupt the maintenance of continuous attention that is needed for efficient math problem solving among students with high math anxiety. Thus, it is important for educators to consider practices that may dampen the distracting effect of various task-relevant and task-irrelevant distractors on the math performance among students who are highly math anxious.

Tianyu Li https://orcid.org/0000-0002-7495-8022
James R. Brockmole https://orcid.org/0000-0003-3227-1078
Sara A. Hart https://orcid.org/0000-0001-9793-0420
Zhe Wang https://orcid.org/0000-0002-3939-4452

We thank the participating families, research assistants, and funding agency. This research was supported by the National Science Foundation Grant CAREER DRL-1750025 awarded to Zhe Wang. The content is the responsibility of the authors and does not represent the official views of the funding agency.

Zhe Wang designed the study. Tianyu Li, Michaela Quintero, Michael Galvan, Sierra Shanafelt, and Leslie M. Hasty collected and processed the data. Tianyu Li and Zhe Wang conducted the analyses and drafted the article. Derek P. Spangler, Ian M. Lyons, James R. Brockmole, and Sara A. Hart provided constructive feedback on the design of the study. All authors provided constructive feedback on the development of this article.

De-identified data, analyses codes, and materials are available at https://doi.org/10.17605/OSF.IO/V3GCJ.

The data are available at https://doi.org/10.17605/OSF.IO/V3GCJ

The experiment materials are available at https://doi.org/10.17605/OSF.IO/V3GCJ

Correspondence concerning this article should be addressed to Zhe Wang, Department of Human Development and Family Sciences, Texas Tech University, 1301 Akron Avenue, Box 41230, Lubbock, TX 79409-1230, United States. Email: zhe.wang@ttu.edu

Keywords: attentional bias, attentional control theory, elementary and middle school students, eye-tracking, math anxiety

Supplemental materials: https://doi.org/10.1037/edu0000759.supp

Math anxiety (MA) is an unpleasant emotion associated with the anticipation of or participation in math activities (Ashcraft, 2002; Richardson & Suinn, 1972). Students with higher MA often avoid math-related courses and career paths and have poorer math performance (Barroso et al., 2021; Caviola et al., 2022; Chipman et al., 1992; Hembree, 1990; LeFevre et al., 1992; Namkung et al., 2019). Thus, MA is often detrimental to students' math learning and pursuit of science, technology, engineering, and mathematical (STEM) professional goals (Foley et al., 2017). Although there is ample evidence on the long-term negative consequences of MA on math learning (Dowker et al., 2016), much less is known about the cognitive mechanisms underlying the impaired math performance among highly math anxious students. According to the attentional control theory (ACT; Eysenck et al., 2007), anxiety undermines cognitive performance by inducing an attentional bias to distractors during problem solving, which occupies the cognitive resources required for task-related processing. Although the ACT provides a framework to investigate the effects of anxiety on cognitive processing, it is unclear whether the proposed mechanism accounts for the anxiety-performance association in the math domain. Importantly, there is a paucity of studies that examine the cognitive mechanisms of the association between MA and math performance in children, which limits our understanding of the early emerging math performance gaps between highly math anxious students and their nonanxious counterparts. The current study fills these gaps by investigating whether the attentional mechanism proposed in the ACT explains the association between MA and math performance in elementary and middle school students.

The Link Between Math Anxiety and Math Performance

MA is generally negatively associated with math performance in children and adults (Barroso et al., 2021; Caviola et al., 2022; Namkung et al., 2019). Three models have been proposed to explain this negative association: the deficit model, the debilitating anxiety model, and the reciprocal model (Carey et al., 2016; Ramirez et al., 2018). The deficit model states that having poor math performance in early school years elicits MA (Carey et al., 2016; Ramirez et al., 2018). The debilitating anxiety model includes two accounts: the learning avoidance account and the cognitive interference account. The learning avoidance account argues that students with higher MA are more likely to avoid math learning and practicing, which deprives them of opportunities to improve math skills (Chipman et al., 1992; Hembree, 1990; John et al., 2020; Quintero et al., 2022). The cognitive interference account postulates that the impaired math performance among individuals with high MA often do not reflect their true math abilities; rather, high MA competes for cognitive resources in the moment of problem solving, which temporarily diminishes performance ability among individuals with high MA (Ashcraft & Krause, 2007; Beilock & Carr, 2005; Ramirez et al., 2016). Finally, the reciprocal model argues that poor math performance elicits MA, which in turn impairs subsequent math performance by way of avoidance and cognitive interference (Carey et al., 2016; Ramirez et al., 2018). The present study focuses on investigating the mechanism proposed in the cognitive interference account.

The cognitive interference account has received some empirical support. As one example, in one study, when adults were asked to solve arithmetic problems while performing a secondary memory task, individuals with high versus low MA differed only slightly when the memory load was low but differed substantially when the memory load was high, suggesting faster depletion of working memory in adults with high MA (Ashcraft & Kirk, 2001). The Ashcraft and Kirk (2001) study was conceptualized based on the Processing Efficiency Theory (Eysenck & Calvo, 1992), which argues that individuals with high anxiety experience worries and intrusive thoughts that compete with the ongoing tasks for the limited working memory resources and cause performance deficits such as poor accuracy or slow performance. The Processing Efficiency Theory has subsequently evolved into the ACT (Eysenck et al., 2007). One major extension of this theory concerns external distractors that, like internal distractors of intrusive thoughts, interfere task performance. The ACT posits that anxiety impairs cognitive performance by inducing an attentional bias, which involves reduction of goal-directed attentional control and activation of stimulus-driven attention to distracting stimuli (even more so for threat-related distractors; Eysenck et al., 2007). Empirically, individuals with high general anxiety are found to often demonstrate reduced processing efficiency as a result of an automatic attentional bias toward distractors during information processing (Bar-Haim et al., 2007; Dudeney et al., 2015; Eysenck et al., 2007; MacLeod et al., 2019).

In line with the ACT, several studies have pinpointed attentional control as a possible target of MA attack by showing that the deteriorating effect of MA on math performance may be due to an inability to inhibit attention to external distractors among persons with high MA. For example, Hopko and colleagues (1998) found that adults with higher MA took longer and made more errors in a passage comprehension test when math-related distractor words were inserted into the passages, suggesting that adults with higher MA were less capable of inhibiting their attention to task-irrelevant math distractors. Similarly, adults with higher MA took longer to respond to incongruent trials in a numerical Stroop task compared with adults with lower MA (Suárez-Pellicioni et al., 2015). Additionally, individuals with different levels of MA may differ in orienting attention. Using the dot-probe task, some researchers found that adults with higher MA exhibited more initial avoidance of math stimuli (Pizzie & Kraemer, 2017), whereas other researchers found that adults with higher MA showed more initial engagement toward math stimuli (Rubinsten et al., 2015). Together, these findings suggest that a stimulus-driven (rather than goal-driven) attention interferes with cognitive performance of adults with high MA when math information is presented as task-irrelevant distractors. According to the ACT, this task-irrelevant math-related information may be particularly distracting to individuals with higher MA, which draws their attention away from task-relevant information processing.

Knowledge Gaps in the Current Literature

Although the emerging literature highlights impaired attentional control as a candidate cognitive mechanism underlying the negative association between MA and math performance, several critical limitations in the existing paradigms leave important knowledge gaps to be addressed. First, most cognitive tasks in the existing studies lack ecological validity because they do not resemble the math problem-solving tasks that children encounter in their educational settings. In the dual-task paradigm, individuals need to solve math problems and remember sequences of letters simultaneously (Ashcraft & Kirk, 2001). In the dot probe task, math problem-solving is secondary to the primary goal of identifying the shape of the dot (Rubinsten et al., 2015). In the numerical Stroop task, individuals need to compare a pair of numbers for their magnitude differences while ignoring their font size differences (Suárez-Pellicioni et al., 2015). These tasks are designed with a dual-task demand, in which a nonmath task competes with the math-task for the limited cognitive resources. As such, they differ critically from the math tasks in daily educational settings where math problem solving is the sole focus.

Relatedly, although prior studies reveal an attentional bias in individuals with high MA toward math stimuli, these studies do not inform us whether such an attentional bias impairs math performance. Specifically, previous studies often incorporate math information as task-irrelevant distractors into nonmath tasks. For example, Hopko and colleagues (1998) used a reading comprehension task in which math words were inserted as distractors into the reading materials. To understand whether an attentional bias accounts for the impaired *math* performance among individuals with high MA, we need to investigate their attentional processes in a math task, rather than a nonmath task.

A second limitation in the current literature is the sole reliance on performance outcomes, such as accuracy and reaction time (RT), to measure attention. This is problematic because these performance outcomes do not measure attention continuously; rather, they provide only a summary snapshot of how well and how quickly an individual completes a task, both of which come after the processing is completed. These measures do not capture the temporal and spatial distribution of attention while the processing is happening throughout the task (Armstrong & Olatunji, 2012). As a result, it is unclear whether MA impairs math performance by way of sustained attentional bias toward distractors throughout the task or orienting attentional bias at the initial stage of information processing. Therefore, a better approach is needed to measure attention more directly and continuously during problem solving.

The eye-tracking approach may help address this limitation. Compared with performance outcomes, the eye-tracking approach gives a real-time measure of cognitive processing, which more directly and precisely measures how attention is allocated during problem solving (Duchowski, 2017; Eggert, 2007; Mock et al., 2016). An eye-tracker captures the spatial and temporal features of eye movements indicative of the location and duration of attention (Strohmaier et al., 2020; Yiend, 2010). One recent study measured adults' eye movement during an arithmetic verification task (Hunt et al., 2015). This study found that higher MA was associated with longer RT, but this negative association was not mediated by the attention to the arithmetic problems as captured by a variety of eye-movement measures (Hunt et al., 2015). These findings were interpreted as evidence against the cognitive interference account. However, an important component missing from this design is external distracting stimuli that could potentially induce attentional bias during problem solving.

Finally, almost all existing studies used adult samples, resulting in a lack of understanding of the attentional processes in highly math anxious children. In the general anxiety literature, findings regarding the attentional bias toward distracting stimuli are well-established in the adult population (Armstrong & Olatunji, 2012), but findings in anxious children and adolescents are mixed (Dudeney et al., 2015; Lisk et al., 2020). This reveals the possibility that unique attentional mechanisms may be present in childhood but not at other developmental periods. Therefore, there is a substantial need to investigate the attentional mechanisms underlying the MA-math performance association in early developmental stages.

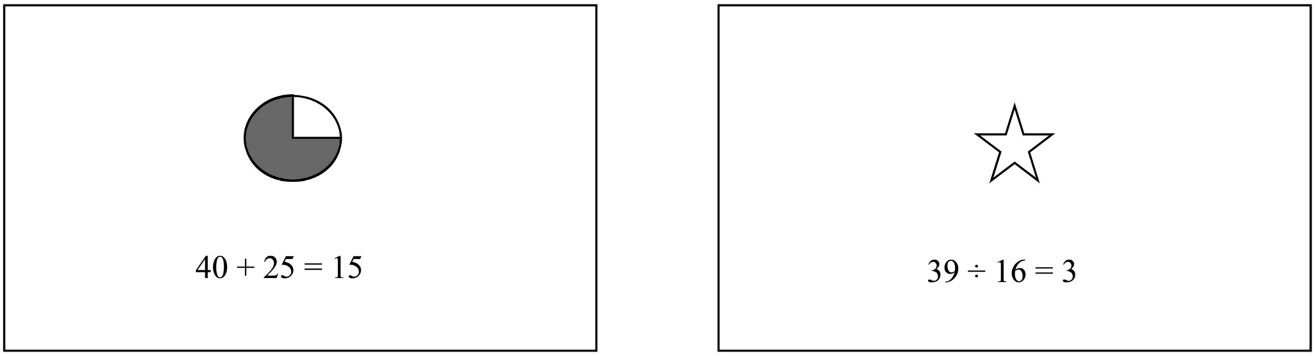
The Present Study

The present study aims to advance our understanding of the cognitive mechanisms underlying the impaired math performance in highly math anxious students. We focus on investigating impaired attentional control (as indicated by the presence of an attentional bias toward distracting stimuli) as the mediator in the association between MA and math performance. To address the gaps in the literature, we used an eye-tracking approach to measure real-time attention allocation in an ecologically valid timed math task in a sample of elementary and middle school students. In this task, students solved a series of arithmetic problems within a time limit (Murphy & Mazzocco, 2008). This task resembles the real-world problem-solving tasks that students are familiar with, where their sole focus is on solving the math problems. Performance on this task has been shown to correlate moderately positively with standardized math achievement test scores (Wang et al., 2015), which further demonstrates the ecological validity of this math task. Additionally, by using a math task (rather than a nonmath task), we can examine whether students with higher MA exhibit more attentional bias during math problem solving, and whether such an attentional bias predicts their poorer math performance.

To examine the type of distractors that may induce attentional bias in highly math anxious students, we incorporated two conditions in this math task (see Figure 1). One condition includes a rotating star, which is completely irrelevant to the task (i.e., task-irrelevant distractor). The other condition includes a circular countdown timer that indicates the amount of time left for each problem (i.e., task-relevant distractor). We operationalize the task-relevant distractor as a distractor that emphasizes or makes salient the timed nature of the task. This operationalization is used because students are often assessed by timed tests in their daily classroom settings. As such, salient time pressure is an ecologically relevant distractor that warrants further examination. Additionally, it has been suggested that the pressure to finish timed math tasks disrupts attentional control and yields performance decline among highly math anxious individuals (Ashcraft, 2002; Plass & Hill, 1986). Therefore, salient time pressure may be a task-relevant distractor that heightens the disruptive effect of MA on math performance.

We used eye-tracking measures to assess students' attention during problem solving. Specifically, the onset of the first fixation (i.e.,

Figure 1
Illustration of the Problem Verification Task



(a) Timer block: The timer indicates the time left for a problem.

(b) Star block: The rotating star is irrelevant to the task.

first fixation onset) in an area is often considered an indicator of initial orienting attention to stimuli in that area (Bar-Haim et al., 2007). The total number (i.e., fixation count) and the cumulative duration of fixations (i.e., dwell time) in an area indicate one's overall level of attention to stimuli within that area (Liang et al., 2017). Hence, fixation count and dwell time are indicators of the overall importance of a region to an individual in a task. By using these eye movement indicators, we can examine whether students with higher MA exhibit an orienting attentional bias at the initial stage of information processing and/or a sustained attentional bias throughout the task toward the distractors and/or the math problems.

In summary, the current study examined whether students with higher MA exhibited more attentional control deficits while solving math problems and whether such attentional control deficits predicted their performance on this math task. Although the ACT argues that anxiety mainly affects performance efficiency, which is a combination of accuracy and speed (Eysenck et al., 2007), we examined accuracy and RT as separate indicators of task performance, because individuals with higher MA may exhibit several possible performance profiles. For example, they may be motivated to engage in additional effort (i.e., longer RT) to perform at the same accuracy level as those with lower MA (Eysenck et al., 2007). They may sacrifice accuracy for speed (Ashcraft & Faust, 1994). They may even show deficits in both accuracy and speed (Barroso et al., 2021; Caviola et al., 2022; Namkung et al., 2019). These different possibilities suggest that examining accuracy and RT as two separate performance indicators, rather than as a single efficiency score, affords us greater specificity in understanding the performance profiles of students with varying levels of MA. Drawing on the ACT and empirical findings in the MA literature, we hypothesized that,

1. Higher MA would be associated with lower performance accuracy and longer reaction time in both the timer and star conditions.
2. Higher MA would be associated with lower levels of orienting and overall attention to the arithmetic problems and higher levels of orienting and overall attention to the distractors in both the timer and star conditions.
3. Both orienting and overall attention to the arithmetic problems and distractor would mediate the negative association between MA and performance accuracy and the positive association between MA and reaction time in both the timer and star conditions.

Method

Participants

The sample consisted of 207 families participating in an ongoing longitudinal study. Families with children who were between 3rd and 6th grade at the time of initial assessment were recruited from a West Texas community by way of digital advertisement, flyers, and community events. Participants' ages ranged from 8 to 12 years (M = 10.18; SD = 1.04; 50% female). The sample racial composition was 68% White, 8% African American, 6% Asian, 2% Native American or Alaska Native, and 15% other. Families of Hispanic origin comprised 38% of the sample. In terms of family income, 23% of families had an annual household income less than $40,000 and 27% of families had an annual household income more than $100,000. Regarding parental educational level, 10% of the parents completed their high school education or less, 18% of the parents attended college without graduating, 35% of the parents graduated from college, and 36% of the parents attended graduate or professional school education.

Procedure

Each family visited the lab for three hours for their initial assessment. First, each participating child completed a series of computerized tasks, including the Problem Verification task (PVT) used in the present study and several executive function tasks not used here. Eye movement data were collected during the PVT. Then, each child completed standardized reading and math achievement testing. Finally, each child completed a series of questionnaires to measure their MA and general anxiety. The experimental protocols were approved by the Institutional Review Board of Texas Tech University.

Measures

Problem Verification Task

In the PVT (adapted from Murphy & Mazzocco, 2008), participants were asked to determine whether an arithmetic equation (e.g., "33 − 3 = 30") was correct or incorrect by pressing two keys on a standard computer keyboard, with the "z" key indicating "incorrect" and the "?" key indicating "correct." Although participants were given 10s to respond to each problem, they were encouraged to provide their responses as quickly and as accurately as possible.

Each participant completed 134 trials in two blocks. The 66 trials per block included a mixture of addition and subtraction problems (up to three-digit integers) and multiplication and division problems (up to two-digit integers). In each block, 32 trials presented an equation with the correct solution, whereas 34 trials presented an equation with an incorrect solution. Problems presented in the two blocks were matched on the operation, difficulty level, and correct/incorrect solution. The presentation order of the two blocks was randomized across participants, and the presentation order of the trials within each block was fixed for all participants. Each equation was presented together with a distractor (see Figure 1), with the distractor being randomly positioned above or below the equation.

In the task-relevant distractor block, each trial incorporated a circular timer. In the task-irrelevant distractor block, each trial incorporated a rotating star. A circular timer was chosen over a digital timer because (a) the latter presents numbers which may compete with the numbers in the arithmetic problems, and (b) the former presents a better visual control for the rotating star (i.e., both move circularly). Participants were introduced to the distractors by (a) receiving the verbal instruction "the circular timer indicates the amount of time left for each problem and the rotating star has absolutely nothing to do with the problem," and (b) completing one practice trial for each condition at the beginning of the task.

To assess participants' performance in each block, accuracy was calculated as the number of correct responses divided by the total number of trials, and RT was calculated by taking the average RT across all trials (including trials with a correct and an incorrect response) in milliseconds.[1] We converted the units from milliseconds to seconds in the mediation analyses to facilitate the interpretation of parameter estimates.

The PVT was programmed in E-Prime 3.0 (Psychology Software Tools Inc., 2016). The stimuli were presented on a 24-in. monitor with the resolution set to 1,920 by 1,080 pixels. The font of the equation was in Cambria Math 65. The size of the timer was 172.8 by 140.4 pixels, and the size of the rotating star was 192 by 162 pixels. The timer was set to be slightly smaller than the star to make these two distractors visually comparable. The horizontal center of the equation and distractor was set at 50% and the vertical center was set at 33% or 67% depending on the relative positions of the equation and distractor in each trial. A central fixation point ("+"; font Consolas, size 45 in bold) was presented for 500 or 800 milliseconds to recenter gaze attention prior to each trial. The presentation duration of the fixation point was randomized across trials. During the task, the keyboard was covered by an opaque box to encourage participants to focus on the monitor instead of looking down at the keyboard.

Eye-Tracking

Eye movements were recorded during the PVT using an Eyelink 1000 Plus eye tracking system (SR Research, 2016). The eye-tracker was operated in the remote mode that sampled eye movements at a rate of 1000 Hz. A target sticker was attached to each participant's forehead to enable tracking of head position in situations when gaze was lost, which can happen when a participant blinks or makes a sudden movement. By adjusting the height of the seat and the position of each participant, (a) the participant's eyes were aligned with the top quarter of the monitor and (b) the distance between the participant's tracked eye and the eye-tracker camera was approximately 55 cm to 60 cm. The distance between the monitor and eye-tracker was 51 cm. Therefore, the total distance between the tracked eye and the monitor was approximately 106 to 111 cm.

Prior to the PVT, a 13-point calibration and validation procedure was completed to map the output of the eye tracker against spatial position on the monitor. The acceptable spatial error in the validation was set at below .5° of visual angle for the average error and below 1° of visual angle for the maximum error. By default, each participant's right eye was tracked (n = 160). When tracking the right eye invoked technical issues or yielded errors higher than the predetermined threshold, the left eye was recorded instead (n = 29).

Eye movement data processing was completed in Data Viewer (SR Research, 2016). Two interest areas (IAs) were created in each trial, one for the equation and one for the distractor (i.e., timer/star). The IAs for the distractors were of the same sizes as the distractors. For the equations, the sizes of the IAs varied across trials depending on the length of the equation,[2] but each IA was tight against each equation. Three eye-movement indicators were considered for each IA in each trial, including: (a) first fixation onset: the time it takes till the initial fixation on the IA; (b) fixation count: total number of fixations within the IA; and (c) dwell time: the sum of the fixation durations within the IA. For each indicator, we created a summary score by taking an average of the scores across all trials within each block.

Math Anxiety

MA was measured using the Mathematics Anxiety Scale for Children (Chiu & Henry, 1990). This scale contains 22 items that ask participants to rate how nervous they feel in different math-related situations, such as "reading and interpreting graphs or charts," or "taking a quiz in a math class." Each item was rated on a 4-point Likert scale from 1 = *not nervous* to 4 = *very very nervous*. A composite MA score was created by taking the average of the 22 items. A higher score represented a higher level of MA. Cronbach's alpha for this scale was .92.

---

[1] A separate set of analyses were conducted in which RT was calculated using only trials with a correct response. Results remain essentially unchanged.

[2] The size of the equation IA varies depending on the length of the equation because each digit and operation sign is of the same font and size. Therefore, the equation 20 + 30 = 50 is naturally longer than the equation 2 + 3 = 5. This variation in IA size is constant across all participants. Thus, it does not affect the analyses of individual differences.

Covariates

Each student reported their sex (1 = *male*, 2 = *female*) and grade level. To get a more nuanced measure of within-grade level variance over the course of each academic year, we calculated grade with month based on the current grade plus the number of school months as a decimal point ranging from 1 to 9 (e.g., a 5th grader who participated in the study in November was in grade 5.3); summertime was counted as .9.

General anxiety was measured using six items from the Spence Children's Anxiety Scale (Spence, 1997). Participants were asked to rate how often they experience anxious feelings on a 4-point-Likert scale from 0 = *never* to 3 = *always*. One sample item is "I worry about things." Cronbach's alpha for this scale was .82.

Statistical Analysis

Data preparation, descriptive analyses, and correlations were completed using IBM SPSS Statistics (Version 25, IBM Corp, 2017). Structural equation modeling analyses were completed in Mplus V8.6 (Muthén & Muthén, 1998–2017). For each block, we tested two mediation models (Figure 2a–2d), with one examining orienting attention (i.e., first fixation onset) as the mediator and the other examining overall attention (i.e., fixation count and dwell time) as the mediator. First fixation onset was examined as a manifest indicator of orienting attention whereas fixation count and dwell time were used to form a latent overall attention factor. Mediation effects were tested using the bootstrap confidence intervals with 10,000 bootstrap samples. Student sex, grade with month, and general anxiety were controlled as covariates in all the mediation models.

A total of 18 participants did not have eye movement data owing to technical problems. In addition, to ensure the quality of the results, participants who failed to look at the equation IA at all on more than 40% of trials were removed from further analyses (n = 15).[3] We also excluded participants who were not engaged in the activity (n = 10), based on the following criteria: (a) having a combination of both low accuracy scores ($\leq$ .25) and short RT ($\leq$ 2,500 ms) and (b) exhibiting consistent off-task behaviors during the PVT. There was no mean difference in the MA score between participants who were included (M = 1.89, SD = .54) in and those who were excluded (M = 2.03, SD = .55) from the analyses, $t(203) = -1.50$, p = .14. The sample size for the final analyses was 168.

Transparency and Openness

We report all manipulations and measures relevant to the present study, as well as criteria for data exclusions. De-identified data, analysis scripts, and materials are available at https://doi.org/10.17605/OSF.IO/V3GCJ. The present design and analyses were not preregistered.

Results

Table 1 shows the descriptive statistics of the main study variables. We conducted a series of paired sample t tests to examine differences in attention and performance between the timer and the star blocks (see Table 2). Students performed more accurately in the timer block than the star block. In terms of attention to the distractor, students had a significantly slower first fixation on the timer than the star. Additionally, students fixated significantly longer and more frequently on the timer than the star.

Owing to the large number of variables, their correlations are shown in Table S1 in the online supplemental materials. The correlation patterns were highly similar across the timer and star blocks. Specifically, MA was correlated with accuracy modestly negatively, and with RT modestly positively. Regarding correlations between MA and attention, MA was positively correlated with fixation count and dwell time in the distractor area. MA was generally not correlated with attention in the equation area. In terms of the correlations between attention and performance, the three attention indicators in both IAs were generally positively associated with RT and negatively associated with accuracy.

The four mediation models described in the statistical analysis section were used to test hypotheses 1–3. The two models examining the mediating role of orienting attention (Figure 2a and 2c) were saturated, for which model fit could not be evaluated. The two models[4] examining the mediating role of overall attention (Figure 2b and 2d) had adequate fit (Timer block: $\chi^2[14] = 26.89$, p = .02; CFI = .98; RMSEA = .08; Star block: $\chi^2[14] = 23.22$, p = .06; CFI = .99; RMSEA = .06). Students' sex, grade level, and general anxiety were included as covariates in all models and their estimated effects are presented in Supplemental Table S2.

To test hypothesis 1 (Higher MA would be associated with lower performance accuracy and longer RT in both the timer and star conditions), we examined the total effects (i.e., a combination of direct and indirect effects) of MA on performance accuracy and RT in the four mediation models. In the timer block (Figure 2a and 2b), there was a significant total effect of MA on accuracy ($\beta = -.23$, 95% bootstrap CI [$-.36$, $-.11$]) and RT ($\beta = .16$; 95% bootstrap CI [.00, .32]). In the star block (Figure 2c and 2d), there was a significant total effect of MA on accuracy ($\beta = -.34$; 95% bootstrap CI [$-.48$, $-.20$]). The total effect of MA on RT did not reach statistical significance in the star block ($\beta = .14$; 95% bootstrap CI [$-.02$, .29]), but its magnitude resembled the total effect of MA on RT in the timer block.

To test hypothesis 2 (Higher MA would be associated with less orienting and overall attention to the arithmetic problems and more orienting and overall attention to the distractors in both the timer and star conditions), we examined the predictive paths from MA to attention indicators in the four mediation models. In the timer block, MA was not associated with orienting attention toward either the equation or the distractor (Figure 2a), suggesting that students with higher MA did not differ from students with lower MA in their initial stage of information processing. While MA was not associated with overall attention to the equation, it was positively associated with overall attention to the timer (Figure 2b), suggesting that students with higher MA paid more attention overall to the task relevant distractor. The results in the star block resemble those in the timer block. Specifically, MA was not associated with orienting attention toward either the equation or

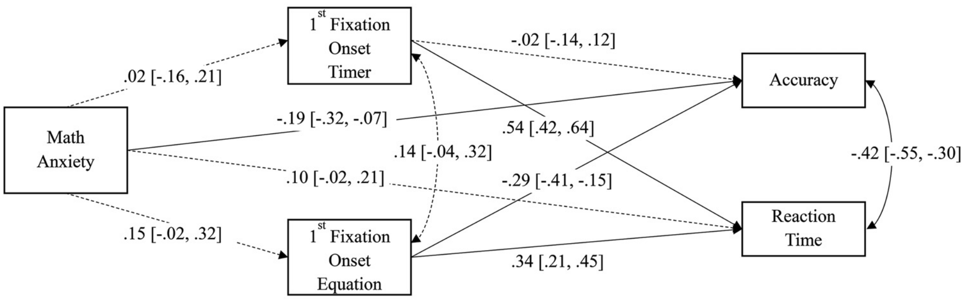
---

[3] We also conducted additional analyses with these participants included. Results remain essentially the same.

[4] Fixation count and dwell time for the timer and equation are highly correlated, which causes a poor model fit and an estimation of negative residual variance for dwell time. To improve model fit and remedy the estimation problem, we constrained the residual variance for dwell time to be zero.

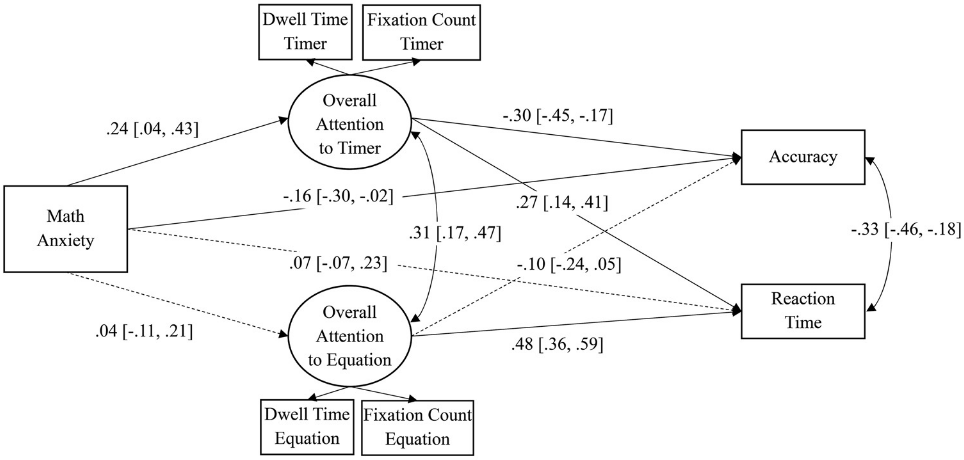
Figure 2
Mediation Models

a. Math Anxiety Predicts PVT Performance via First Fixation Onset in the Timer Block



Indirect Effects:
Math Anxiety → 1st Fixation Onset to Timer → Accuracy: .00 [-.02, .01]
Math Anxiety → 1st Fixation Onset to Timer → Reaction Time: .01 [-.08, .12]
Math Anxiety → 1st Fixation Onset to Equation→ Accuracy: -.04 [-.10, .00]
Math Anxiety → 1st Fixation Onset to Equation → Reaction Time: .05 [-.01, .12]

b. Math Anxiety Predicts PVT Performance via Overall Attention in the Timer Block



Indirect Effects:
Math Anxiety → Overall Attention to Timer → Accuracy: -.07 [-.13, -.01]
Math Anxiety → Overall Attention to Timer → Reaction Time: .06 [.01, .12]
Math Anxiety→Overall Attention to Equation→Accuracy: -.00 [-.03, .02]
Math Anxiety→Overall Attention to Equation→Reaction Time: .02 [-.05, .10]

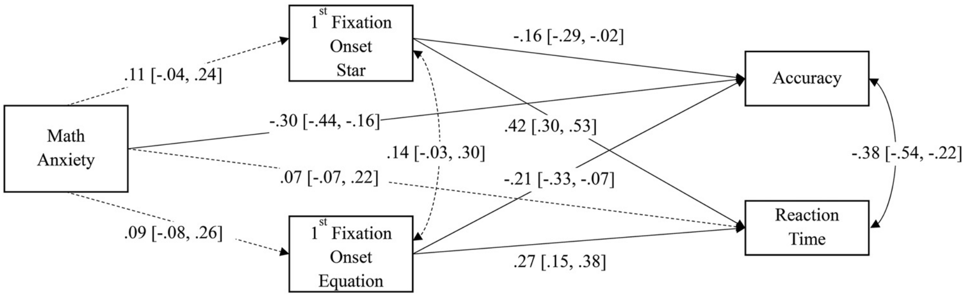
(Figure continues on next page)

the distractor (Figure 2c). Although MA was not associated with overall attention toward the equation, it was positively associated with overall attention to the star (Figure 2d).

To test hypothesis 3 (Both orienting and overall attention to the arithmetic problems and distractor would mediate the negative association between MA and performance accuracy and the positive association between MA and RT in both the timer and star conditions), we examined the indirect effects of MA on accuracy and RT via orienting and overall attention in the equation and distractor areas in the four mediation models. In both the timer and star blocks, orienting attention to neither equation nor the distractor area mediated the association between MA and task performance (Figure 2a and 2c). In both the timer and star blocks, overall attention in the distractor area, but not in the equation area, mediated the associations between MA and accuracy and between MA and RT (Figure 2b and 2d). Specifically, MA significantly positively predicted overall attention to the distractor

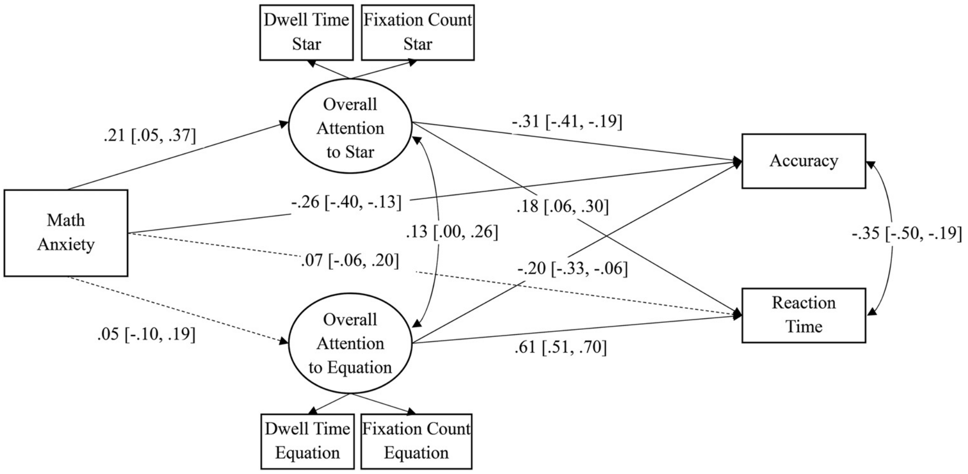
Figure 2. *(continued)*

c. Math Anxiety Predicts PVT Performance via First Fixation Onset in the Star Block



Indirect Effects:
Math Anxiety → 1st Fixation Onset to Star → Accuracy: -.02 [-.05, .01]
Math Anxiety → 1st Fixation Onset to Star → Reaction Time: .04 [-.02, .11]
Math Anxiety → 1st Fixation Onset to Equation→ Accuracy: -.02 [-.07, .02]
Math Anxiety → 1st Fixation Onset to Equation → Reaction Time: .02 [-.02, .08]

d. Math Anxiety Predicts PVT Performance via Overall Attention in the Star Block



Indirect Effects:
Math Anxiety → Overall Attention to Star → Accuracy: -.07 [-.12, -.02]
Math Anxiety → Overall Attention to Star → Reaction Time: .04 [.00, .09]
Math Anxiety→Overall Attention to Equation→Accuracy: -.01 [-.05, .02]
Math Anxiety→Overall Attention to Equation→Reaction Time: .03 [-.06, .12]

Note. (a) Math anxiety predicts Problem Verification task (PVT) performance via first fixation onset in the timer block. (b) Math anxiety predicts PVT performance via overall attention in the timer block. (c) Math anxiety predicts PVT performance via first fixation onset in the star block. (d) Math anxiety predicts PVT performance via overall attention in the star block. Standardized parameter estimates [95% bootstrap confidence intervals] are displayed. Solid lines and bold numbers indicate statistical significance under the Type I error rate of .05; dotted lines indicate nonsignificant paths. Child sex, grade level, and general anxiety were included in the model as covariates but are not shown in the figures for simplicity.

area, suggesting that students with higher MA fixated longer and more frequently on the distractor. In turn, overall attention in the distractor area significantly negatively predicted accuracy and positively predicted RT, suggesting that students with higher MA showed enhanced overall attention to the distractor, which contributed to their less accurate performance and prolonged RT in both blocks.

Discussion

The present study investigated the extent to which impaired attentional control during a math problem-solving task mediated the association between MA and math performance in a sample of elementary and middle school students. Overall, our findings showed that students

Table 1

Descriptive Statistics of Study Variables

Variable	*M*	*SD*	Skewness	Kurtosis	Min	Max
Grade	5.32	.87	0.06	−0.79	3.20	7.10
General anxiety	2.07	.68	1.01	0.95	1.00	4.00
Math anxiety	1.89	.54	0.78	0.52	1.00	3.64
Timer block						
Task performance						
Accuracy	.72	.11	−0.18	−0.12	.42	.97
Reaction time	4,753.75	1,274.62	0.15	−0.35	1,834.20	7,833.95
Attention to distractor						
First fixation onset	3,682.12	1,128.51	0.08	0.22	842.67	7,095.10
Fixation count	0.60	0.38	1.65	4.28	0.02	2.32
Dwell time	210.84	191.68	2.57	9.34	4.12	1,281.35
Attention to equation						
First fixation onset	1,467.51	329.59	1.58	2.75	1,075.08	2,799.61
Fixation count	7.10	2.51	0.16	0.04	0.95	14.80
Dwell time	2,413.55	997.18	0.35	−0.17	346.15	5,102.20
Star block						
Task performance						
Accuracy	.69	.12	−0.17	−0.55	.35	.98
Reaction time	4,820.60	1,367.95	0.12	−0.41	1,729.21	8,253.70
Attention to distractor						
First fixation onset	2,753.79	1,208.29	0.40	−0.72	918.17	5,696.64
Fixation count	0.28	0.18	1.12	1.43	0.00	1.00
Dwell time	73.68	65.62	2.08	5.67	0.00	391.61
Attention to equation						
First fixation onset	1,452.56	305.51	1.18	1.02	1,068.83	2,579.93
Fixation count	7.36	2.74	0.21	−0.22	1.55	15.74
Dwell time	2,585.20	1,115.53	0.25	−0.35	503.59	5,432.12

with higher MA exhibited an attentional bias toward both task relevant and task irrelevant distractors during math problem solving. This attentional bias toward distractors among students with higher MA further contributed to their less accurate and slower performance compared with students with lower MA. Next, we discuss our findings in relevance to each of the three study hypotheses in turn.

Our first hypothesis that higher MA would be associated with lower accuracy and longer RT was partially supported. We found that higher MA was modestly associated with lower accuracy in both the timer and star blocks, consistent with the literature showing impaired math performance among students with high MA (Barroso et al., 2021; Namkung et al., 2019). MA was significantly negatively associated with RT in the timer but not the star block. Although the total effect of MA on RT did not reach statistical significance in the star block, its magnitude resembled the total effect of MA on RT in the timer block, suggesting that the size of the total effect of MA on RT was small in both blocks. Our finding is at odds with a recent eye-tracking study by Hunt and colleagues (2015), which found that MA was associated with RT, but not accuracy, in an arithmetic verification task. This discrepancy may be due to the different types of distractors examined in these two studies. Hunt et al. (2015) did not include external distractors in their arithmetic task, so their highly anxious participants were likely primarily influenced by internal distractors. According to the ACT, internal distractors such as worrying thoughts can motivate highly anxious individuals to invest more cognitive effort (e.g., longer RT) to reach the same accuracy level as observed in those with low anxiety (Eysenck et al., 2007). By contrast, the present study primarily investigated interference from external distractors that may not be as motivating as internal distractors. This

Table 2

Paired Sample t Test: Differences Between Variables in the Timer and Star Blocks

Variable	Timer block *M* (*SD*)	Star block *M* (*SD*)	*t* (*df*)	Cohen's *d*
Task performance				
Accuracy	.72 (.11)	.69 (.12)	5.57 (167)[a]	0.43
Reaction time	4,753.75 (1,274.62)	4,820.60 (1,367.95)	−1.26 (167)	−0.10
Attention to distractor				
First fixation onset	3,670.39 (1,121.57)	2,753.79 (1,208.29)	9.30 (166)[a]	0.72
Fixation count	0.60 (0.38)	0.28 (0.18)	12.60 (167)[a]	0.97
Dwell time	210.84 (191.68)	73.68 (65.62)	10.97 (167)[a]	0.85
Attention to equation				
First fixation onset	1,467.51 (329.59)	1,452.56 (305.51)	0.65 (167)	0.05
Fixation count	7.10 (2.51)	7.36 (2.74)	−1.47 (167)	−0.11
Dwell time	2,413.55 (997.18)	2,585.20 (1,115.53)	−2.52 (167)	−0.20

[a] Statistically significant effects under Type I error rate of .05 after Holm-Bonferroni correction.

may explain why students with higher MA were not only less efficient but also less effective in their performance in the present study.

Our second hypothesis was that higher MA would be associated with less attention to the arithmetic problems and more attention to the distractors. The results partially supported this hypothesis. Inconsistent with this hypothesis, higher MA was not associated with first fixation onset in either block. However, higher MA was associated with more overall attention to both the timer and the star, suggesting that students with higher MA showed a sustained attentional bias toward the distracting information throughout the task, regardless of the distractor types.

Contradictory to our hypothesis, we found that MA was not associated with attention to the arithmetic problems. This finding is at odds with the existing literature regarding highly math anxious students' attentional bias toward math-related information in nonmath tasks (Hopko et al., 1998; Rubinsten et al., 2015). This discrepancy may be because the previous studies used tasks in which math information is tangential or irrelevant to the main goal of the tasks (Hopko et al., 1998; Pizzie & Kraemer, 2017; Rubinsten et al., 2015), whereas math-related information in the current investigation is central to the task performance. Thus, although students with higher MA may show heightened attention to math-related information in a nonmath context, they did not appear to exhibit such an attentional bias in a math problem-solving context. Therefore, in a math problem-solving context, the attentional bias mainly associated with impaired math performance among students with high MA was toward distracting information presented along with the math problems, rather than toward the math problems themselves.

Our third hypothesis was that attention to the arithmetic problems and distractors would mediate the association between MA and task performance. The findings partially supported this hypothesis. Contradictory to our hypothesis, attention to the arithmetic problems did not mediate the association between MA and task performance. This finding is consistent with a recent eye-tracking study on adults, which also found that the eye movement measures of attention to arithmetic problems did not mediate the association between MA and performance on an arithmetic verification task (Hunt et al., 2015). However, consistent with this hypothesis, the overall attention to the distractor mediated the negative association between MA and accuracy as well as the positive association between MA and RT in both the timer and star blocks, such that students with higher MA were more engaged with the distractor, which in turn predicted less accurate performance and more prolonged RT. These results largely support the ACT, which argues that anxiety impairs cognitive performance by undermining goal-driven attentional control and promoting stimulus-driven attentional processing (Eysenck et al., 2007). In the present study, the goal-driven attention is directed toward the arithmetic problems, whereas the stimulus-driven attention is directed toward the distractors. Although students with different MA levels did not differ in their total amount of attention allocated to the arithmetic problems, students with higher MA engaged more than students with lower MA in stimulus-driven processing of the distractors. Mentally solving arithmetic problems is challenging and requires continuous concentration on the to-be-solved problem. When students with higher MA frequently checked the distractors, their continuous train of thoughts was likely disrupted, which may have explained their reduced performance accuracy and increased RT, as compared with students with lower MA.

We investigated attentional control as a cognitive mechanism that may explain why students with higher MA underperform on math tasks relative to their peers with lower MA. The present study has numerous strengths to bridge major gaps in the existing literature. First, unlike previous studies that relied on nonmath tasks or dual tasks (e.g., Ashcraft & Kirk, 2001; Hopko et al., 1998; Rubinsten et al., 2015; Suárez-Pellicioni et al., 2015), we used a math problem solving task to examine the role of attentional control. The principal benefits associated with this math task are the ecological validity stemming from its resemblance to math problem solving children regularly experience in their learning settings, and that it allows us to examine whether the impaired attentional control during a math task contributes to high MA students' impaired math performance. Relatedly, we manipulated the saliency of time pressure in the math task, which allowed us to investigate students' attentional bias toward this ecologically relevant distractor. Second, this study is among the first to use eye-tracking to measure attention during a math task. The eye-tracking measures provide a more direct and precise assessment of the temporal (orienting vs. overall attention) and spatial (equation vs. distractor) distribution of attention throughout the task. Finally, the present study used a sample of elementary and middle school students, which provides the first insight into the attentional mechanism underlying the MA–math performance association in early educational stages.

The present study has several limitations that should be addressed in future studies. First, the correlational design prevents definitive causal inferences regarding the association between MA and PVT performance. Although we focused on the predictive effect of MA on math performance, several longitudinal studies suggest that math performance may also predict subsequent MA development (e.g., Gunderson et al., 2018; Ma & Xu, 2004; Wang et al., 2020). Future longitudinal studies should investigate mechanisms that link MA and math performance in both directions. Relatedly, those mechanisms may be subject to developmental and individual differences, which should be examined in future longitudinal studies. For example, several studies have identified subgroups of students, such as mathematically gifted students, whose performance may benefit from moderate levels of MA (Tsui & Mazzocco, 2007; Wang et al., 2015). Future studies should investigate the mechanisms that explain why MA may promote math performance in some students and hinder math performance in others. Third, it has been shown that individuals with high MA show more performance deficits when solving more difficult arithmetic problems, such as problems involving regrouping (i.e., a carry or borrow), because difficult or novel problems place a heavier tax on working memory capacity than easy or overlearned problems (Ashcraft & Krause, 2007). Additionally, some recent evidence suggests that individuals with higher MA approach the most fundamental numerical processing and simple arithmetic differently than individuals with lower MA (Chang et al., 2017; Maloney et al., 2010). An interesting area for future research is to examine whether deficits in attentional control during math problem solving also vary with the degree of math task difficulty. Fourth, although the current problem verification task mimics some types of math tasks children engage with in the educational settings, it may nevertheless differ from the exact arithmetic production tasks commonly used in the classroom (Campbell &

Tarling, 1996). Moreover, the PVT was a low-stake task that students performed in a lab environment. To better understand whether the present findings generalize to classroom settings, future studies should investigate students' math performance on high-stake exams that include arithmetic production problems. Fifth, although the eye tracking measures of attention have many merits, they capture only overt attention not covert attention. Future studies should combine eye tracking measures with other neurological measures such as continuous EEG to assess covert attention (Kulke et al., 2016). Relatedly, the present study of external distractors does not inform us whether and how internal distractors, such as intrusive thoughts, compete with the ongoing task for attentional resources. Finally, the use of the circular timer as a distractor may present challenges for some students, as it took time to figure out what information was conveyed by the timer. It may even be possible that some students viewed decoding the timer as a math problem itself. Future studies should address these issues by manipulating the timing salience in other ways, such as presenting it auditorily.

The present findings offer several important theoretical and practical implications. Our findings reveal that maladaptive attentional patterns during math problem solving contribute to the MA-related math performance deficit. Students with higher and lower MA allocated a similar amount of attention toward the math problems, but students with higher MA were more easily distracted by the presence of distractors. Consequently, difficulties inhibiting attention toward the distractors contributed to the less accurate and slower performance seen among students with higher MA. Our study elucidates that distracting information presented together with the to-be-solved math problems, may compromise continuous attention needed for efficient math problem solving among students with high MA. Theoretically, these results demonstrate the applicability of the ACT (Eysenck et al., 2007) to explaining the anxiety–performance relation in the math domain.

Additionally, our findings reveal that students with higher MA demonstrated enhanced processing of the distractor, regardless of its task relevance, in a timed math task. This finding has important implications for classroom instructional practices. Many classroom exams are timed and administered in a group setting. These assessment environments may induce unsurmountable distractions for students who already dread math, such as being reminded of the timed nature of the task or seeing people walk around in the classroom. If these distractions prevent these students from concentrating on solving the math problems without interruption, impaired performance may inaccurately underrepresent these students' true math abilities. It is important for educators to consider what classroom practices they use (e.g., more use of untimed task and individually administered assessment) that may dampen the effect of various distractors on math performance among students with high MA. Such practices may not only provide a more accurate assessment of high MA students' math abilities but may also create a more equitable learning environment.

References

Armstrong, T., & Olatunji, B. O. (2012). Eye tracking of attention in the affective disorders: A meta-analytic review and synthesis. *Clinical Psychology Review*, *32*(8), 704–723. https://doi.org/10.1016/j.cpr.2012.09.004

Ashcraft, M. H. (2002). Math anxiety: Personal, educational, and cognitive consequences. *Current Directions in Psychological Science*, *11*(5), 181–185. https://doi.org/10.1111/1467-8721.00196

Ashcraft, M. H., & Faust, M. W. (1994). Mathematics anxiety and mental arithmetic performance: An exploratory investigation. *Cognition and Emotion*, *8*(2), 97–125. https://doi.org/10.1080/02699939408408931

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General*, *130*(2), 224–237. https://doi.org/10.1037/0096-3445.130.2.224

Ashcraft, M. H., & Krause, J. A. (2007). Working memory, math performance, and math anxiety. *Psychonomic Bulletin & Review*, *14*(2), 243–248. https://doi.org/10.3758/BF03194059

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: A meta-analytic study. *Psychological Bulletin*, *133*(1), 1–24. https://doi.org/10.1037/0033-2909.133.1.1

Barroso, C., Ganley, C. M., McGraw, A. L., Geer, E. A., Hart, S. A., & Daucourt, M. C. (2021). A meta-analysis of the relation between math anxiety and math achievement. *Psychological Bulletin*, *147*(2), 134–168. https://doi.org/10.1037/bul0000307

Beilock, S. L., & Carr, T. H. (2005). When high-powered people fail: Working memory and "choking under pressure" in math. *Psychological Science*, *16*(2), 101–105. https://doi.org/10.1111/j.0956-7976.2005.00789.x

Campbell, J. I. D., & Tarling, D. P. M. (1996). Retrieval processes in arithmetic production and verification. *Memory & Cognition*, *24*(2), 156–172. https://doi.org/10.3758/BF03200878

Carey, E., Hill, F., Devine, A., & Szücs, D. (2016). The chicken or the egg? The direction of the relationship between mathematics anxiety and mathematics performance. *Frontiers in Psychology*, *6*, 1987. https://doi.org/10.3389/fpsyg.2015.01987

Caviola, S., Toffalini, E., Giofrè, D., Ruiz, J. M., Sz$\H{\text{ű}}$cs, D., & Mammarella, I. C. (2022). Math performance and academic anxiety forms, from sociodemographic to cognitive aspects: A meta-analysis on 906,311 participants. *Educational Psychology Review*, *34*(1), 363–399. https://doi.org/10.1007/s10648-021-09618-5

Chang, H., Sprute, L., Maloney, E. A., Beilock, S. L., & Berman, M. G. (2017). Simple arithmetic: Not so simple for highly math anxious individuals. *Social Cognitive and Affective Neuroscience*, *12*(12), 1940–1949. https://doi.org/10.1093/scan/nsx121

Chipman, S. F., Krantz, D. H., & Silver, R. (1992). Mathematics anxiety and science careers among able college women. *Psychological Science*, *3*(5), 292–296. https://doi.org/10.1111/j.1467-9280.1992.tb00675.x

Chiu, L. H., & Henry, L. L. (1990). Development and validation of the Mathematics Anxiety Scale for Children. *Measurement and Evaluation in Counseling and Development*, *23*(3), 121–127.

Dowker, A., Sarkar, A., & Looi, C. Y. (2016). Mathematics anxiety: What have we learned in 60 years? *Frontiers in Psychology*, *7*, 508. https://doi.org/10.3389/fpsyg.2016.00508

Duchowski, A. T. (2017). *Eye tracking methodology: Theory and practice*. Springer. https://doi.org/10.1007/978-3-319-57883-5

Dudeney, J., Sharpe, L., & Hunt, C. (2015). Attentional bias towards threatening stimuli in children with anxiety: A meta-analysis. *Clinical Psychology Review*, *40*, 66–75. https://doi.org/10.1016/j.cpr.2015.05.007

Eggert, T. (2007). Eye movement recordings: Methods. *Neuro-Ophthalmology*, *40*, 15–34. https://doi.org/10.1159/000100347

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion*, *6*(6), 409–434. https://doi.org/10.1080/02699939208409696

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*(2), 336–353. https://doi.org/10.1037/1528-3542.7.2.336

Foley, A. E., Herts, J. B., Borgonovi, F., Guerriero, S., Levine, S. C., & Beilock, S. L. (2017). The math anxiety-performance link: A global phenomenon. *Current Directions in Psychological Science*, *26*(1), 52–58. https://doi.org/10.1177/0963721416672463

Gunderson, E. A., Park, D., Maloney, E. A., Beilock, S. L., & Levine, S. C. (2018). Reciprocal relations among motivational frameworks, math anxiety, and math achievement in early elementary school. *Journal of Cognition and Development*, *19*(1), 21–46. https://doi.org/10.1080/15248372.2017.1421538

Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. *Journal for Research in Mathematics Education*, *21*(1), 33–46. https://doi.org/10.5951/jresematheduc.21.1.0033

Hopko, D. R., Ashcraft, M. H., Gute, J., Ruggiero, K. J., & Lewis, C. (1998). Mathematics anxiety and working memory: Support for the existence of a deficient inhibition mechanism. *Journal of Anxiety Disorders*, *12*(4), 343–355. https://doi.org/10.1016/S0887-6185(98)00019-X

Hunt, T. E., Clark-Carter, D., & Sheffield, D. (2015). Exploring the relationship between mathematics anxiety and performance: An eye-tracking approach. *Applied Cognitive Psychology*, *29*(2), 226–231. https://doi.org/10.1002/acp.3099

IBM Corp. (2017). *IBM SPSS Statistics for Windows (Version 25.0)* [Computer Software]. https://www.ibm.com/analytics/spss-statistics-software

John, J. E., Nelson, P. A., Klenczar, B., & Robnett, R. D. (2020). Memories of math: Narrative predictors of math affect, math motivation, and future math plans. *Contemporary Educational Psychology*, *60*, 101838. https://doi.org/10.1016/j.cedpsych.2020.101838

Kulke, L. V., Atkinson, J., & Braddick, O. (2016). Neural differences between covert and overt attention studied using EEG with simultaneous remote eye tracking. *Frontiers in Human Neuroscience*, *10*, 592. https://doi.org/10.3389/fnhum.2016.00592

LeFevre, J.-A., Kulak, A. G., & Heymans, S. L. (1992). Factors influencing the selection of university majors varying in mathematical content. *Canadian Journal of Behavioural Science*, *24*(3), 276–289. https://doi.org/10.1037/h0078742

Liang, C.-W., Tsai, J.-L., & Hsu, W.-Y. (2017). Sustained visual attention for competing emotional stimuli in social anxiety: An eye tracking study. *Journal of Behavior Therapy and Experimental Psychiatry*, *54*, 178–185. https://doi.org/10.1016/j.jbtep.2016.08.009

Lisk, S., Vaswani, A., Linetzky, M., Bar-Haim, Y., & Lau, J. Y. F. (2020). Systematic review and meta-analysis: Eye-tracking of attention to threat in child and adolescent anxiety. *Journal of the American Academy of Child and Adolescent Psychiatry*, *59*(1), 88–99. https://doi.org/10.1016/j.jaac.2019.06.006

Ma, X., & Xu, J. (2004). The causal ordering of mathematics anxiety and mathematics achievement: A longitudinal panel analysis. *Journal of Adolescence*, *27*(2), 165–179. https://doi.org/10.1016/j.adolescence.2003.11.003

MacLeod, C., Grafton, B., & Notebaert, L. (2019). Anxiety-linked attentional bias: Is it reliable? *Annual Review of Clinical Psychology*, *15*, 529–554. https://doi.org/10.1146/annurev-clinpsy-050718-095505

Maloney, E. A., Risko, E. F., Ansari, D., & Fugelsang, J. (2010). Mathematics anxiety affects counting but not subitizing during visual enumeration. *Cognition*, *114*(2), 293–297. https://doi.org/10.1016/j.cognition.2009.09.013

Mock, J., Huber, S., Klein, E., & Moeller, K. (2016). Insights into numerical cognition: Considering eye-fixations in number processing and arithmetic. *Psychological Research*, *80*(3), 334–359. https://doi.org/10.1007/s00426-015-0739-9

Murphy, M. M., & Mazzocco, M. M. M. (2008). Mathematics learning disabilities in girls with Fragile X or Turner Syndrome during late elementary school. *Journal of Learning Disabilities*, *41*(1), 29–46. https://doi.org/10.1177/0022219407311038

Muthén, L. K. M. & Muthén, B. O. (1998–2017). *Mplus (Version 8.6)* [Computer Software]. https://www.statmodel.com/

Namkung, J. M., Peng, P., & Lin, X. (2019). The relation between mathematics anxiety and mathematics performance among school-aged students: A meta-analysis. *Review of Educational Research*, *89*(3), 459–496. https://doi.org/10.3102/0034654319843494

Pizzie, R. G., & Kraemer, D. J. M. (2017). Avoiding math on a rapid timescale: Emotional responsivity and anxious attention in math anxiety. *Brain and Cognition*, *118*, 100–107. https://doi.org/10.1016/j.bandc.2017.08.004

Plass, J. A., & Hill, K. T. (1986). Children's achievement strategies and test performance: The role of time pressure, evaluation anxiety, and sex. *Developmental Psychology*, *22*(1), 31–36. https://doi.org/10.1037/0012-1649.22.1.31

Psychology Software Tools, Inc. (2016). *E-Prime* (Version 3.0) [Computer software]. https://support.pstnet.com/

Quintero, M., Hasty, L., Li, T., Song, S., & Wang, Z. (2022). A multidimensional examination of math anxiety and engagement on math achievement. *British Journal of Educational Psychology*. Advance online publication. https://doi.org/10.1111/bjep.12482

Ramirez, G., Chang, H., Maloney, E. A., Levine, S. C., & Beilock, S. L. (2016). On the relationship between math anxiety and math achievement in early elementary school: The role of problem solving strategies. *Journal of Experimental Child Psychology*, *141*, 83–100. https://doi.org/10.1016/j.jecp.2015.07.014

Ramirez, G., Shaw, S. T., & Maloney, E. A. (2018). Math anxiety: Past research, promising interventions, and a new interpretation framework. *Educational Psychologist*, *53*(3), 145–164. https://doi.org/10.1080/00461520.2018.1447384

Richardson, F. C., & Suinn, R. M. (1972). The mathematics anxiety rating scale: Psychometric data. *Journal of Counseling Psychology*, *19*(6), 551–554. https://doi.org/10.1037/h0033456

Rubinsten, O., Eidlin, H., Wohl, H., & Akibli, O. (2015). Attentional bias in math anxiety. *Frontiers in Psychology*, *6*, 1539. https://doi.org/10.3389/fpsyg.2015.01539

Spence, S. H. (1997). Structure of anxiety symptoms among children: A confirmatory factor-analytic study. *Journal of Abnormal Psychology*, *106*(2), 280–297. https://doi.org/10.1037/0021-843x.106.2.280

SR Research. (2016). *Eyelink 1000 plus* [Apparatus and software]. https://www.sr-research.com/eyelink1000plus.html

Strohmaier, A. R., MacKay, K. J., Obersteiner, A., & Reiss, K. M. (2020). Eye-tracking methodology in mathematics education research: A systematic literature review. *Educational Studies in Mathematics*, *104*(2), 147–200. https://doi.org/10.1007/s10649-020-09948-1

Suárez-Pellicioni, M., Núñez-Peña, M. I., & Colomé, À. (2015). Attentional bias in high math-anxious individuals: Evidence from an emotional Stroop task. *Frontiers in Psychology*, *6*, 1577. https://doi.org/10.3389/fpsyg.2015.01577

Tsui, J., & Mazzocco, M. M. M. (2007). Effects of math anxiety and perfectionism on timed versus untimed math testing in mathematically gifted sixth graders. *Roeper Review*, *29*(2), 132–139. https://doi.org/10.1080/02783190709554397

Wang, Z., Lukowski, S. L., Hart, S. A., Lyons, I. M., Thompson, L. A., Kovas, Y., Mazzocco, M. M. M., Plomin, R., & Petrill, S. A. (2015). Is math anxiety always bad for math learning? The role of math motivation. *Psychological Science*, *26*(12), 1863–1876. https://doi.org/10.1177/0956797615602471

Wang, Z., Rimfeld, K., Shakeshaft, N., Schofield, K., & Malanchini, M. (2020). The longitudinal role of mathematics anxiety in mathematics development: Issues of gender differences and domain-specificity. *Journal of Adolescence*, *80*, 220–232. https://doi.org/10.1016/j.adolescence.2020.03.003

Yiend, J. (2010). The effects of emotion on attention: A review of attentional processing of emotional information. *Cognition and Emotion*, *24*(1), 3–47. https://doi.org/10.1080/02699930903205698

Received September 27, 2021
Revision received April 12, 2022
Accepted April 14, 2022 ■