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Mindfulness, anxiety, and high-stakes mathematics performance in the laboratory and classroom

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ABSTRACT

Mindfulness enhances emotion regulation and cognitive performance. A mindful approach may be especially beneficial in high-stakes academic testing environments, in which anxious thoughts disrupt cognitive control. The current studies examined whether mindfulness improves the emotional response to anxiety-producing testing situations, freeing working memory resources, and improving performance. In Study 1, we examined performance in a high-pressure laboratory setting. Mindfulness indirectly benefited math performance by reducing the experience of state anxiety. This benefit occurred selectively for problems that required greater working memory resources. Study 2 extended these findings to a calculus course taken by undergraduate engineering majors. Mindfulness indirectly benefited students' performance on high-stakes quizzes and exams by reducing their cognitive test anxiety. Mindfulness did not impact performance on lower-stakes homework assignments. These findings reveal an important mechanism by which mindfulness benefits academic performance, and suggest that mindfulness may help attenuate the negative effects of test anxiety.

1. Introduction

Mindfulness, a mode of attending to present moment experiences without judgment or elaboration (Bishop et al., 2004; Brown & Ryan, 2003, 2004), has been widely shown to benefit psychological well-being and cognitive functioning. For example, mindfulness is associated with reduced stress, stress reactivity, and chronic pain (Creswell & Lindsay, 2014; see Baer, 2003, for a review) as well as decreased anxiety and depression (Brown & Ryan, 2003; Chen et al., 2012; Kumar, Feldman, & Hayes, 2008). Mindfulness is also associated with improved cognitive control abilities, as evidenced by measures of self-regulation (Bowlin & Baer, 2012; Chambers, Gullone, & Allen, 2009; Stanley, Schaldach, Kiyonaga, & Jha, 2011; Tang et al., 2007; Teper, Segal, & Inzlicht, 2013), attention (Chan & Woollacott, 2007; Chiesa, Calati, & Serreti, 2011; Jha, Krompinger, & Baime, 2007; Napoli, Krech, & Holley, 2005; Tang et al., 2007; van Leeuwen, Müller, & Melloni, 2009), and working memory (Chambers, Lo, & Allen, 2008; Jha, Stanley, Kiyonaga, Wong, & Gelfand, 2010; Mrazek, Franklin, Phillips, Baird, & Schooler, 2013). Although mindfulness can be characterized as a trained skill, it is thought to be a capacity that varies between individuals due to a propensity or willingness to devote attention to the present moment (Brown & Ryan, 2003).

Due to its positive impact on emotion regulation and cognitive control, mindfulness has been regarded as foundational to educational practice and a readiness to learn (Bakosh, Snow, Tobias, Houlihan, & Barbosa-Leiker, 2015; Zenner,

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Hermleben-Kurz, & Walach, 2014). Therefore, researchers and educators have become increasingly interested in examining the impact of mindfulness in educational settings (e.g., Davidson et al., 2012; Shapiro, Brown, & Astin, 2011). A few studies have demonstrated a positive relationship between mindfulness and educationally-relevant outcome measures such as grades (e.g., Bakosh et al., 2015; Ramsburg & Youmans, 2014). More commonly, school-based mindfulness interventions lead to improvements on a range of attention, creativity, and social–emotional learning measures (see Zenner et al., 2014). It is theorized that such improvements translate into greater educational outcomes, although this mechanism remains largely untested (Shapiro et al., 2011; but see Mrazek et al., 2013).

In addition to improving cognitive control, mindfulness may improve academic performance by supporting students' ability to cope with anxiety in high-stakes testing situations (Napoli et al., 2005; Shapiro et al., 2011). In both controlled laboratory and educational contexts, we examine the idea that mindfulness improves the emotional response to anxiety-producing testing situations, freeing working memory resources, and leading individuals to perform at a higher level on academic exams. High-stakes tests are prevalent, and the corresponding anxiety is often detrimental to students' academic performance, despite sufficient preparation and learning prior to the test (Naveh-Benjamin, McKeachie, & Lin, 1987). By examining how mindfulness impacts students' response to high-stakes testing conditions, we may better understand the mechanisms by which both mindfulness and anxiety impact cognitive control in academic settings—specifically during test taking. We may also better understand how students can maximally demonstrate their learning in situations in which they often falter.

2. Mindfulness, attention control, and emotion regulation

Mindfulness is associated with decreased negatively-biased cognition and rumination (Frewen, Evans, Maraj, Dozois, & Partridge, 2008; Kiken & Shook, 2012). One proposed explanation for this relationship is that mindful individuals are better at decentering—letting anxious and negative thoughts pass without further elaboration or rumination (Bishop et al., 2004; Ciesla, Reilly, Dickson, Emanuel, & Updegraff, 2012; Evans & Segerstrom, 2011; Kang, Gruber, & Gray, 2013). If mindfulness enables individuals to regulate anxious thoughts, then their working memory may be less likely to be co-opted from the task at hand. Working memory is the mental workspace used to attend to thoughts relevant to the task at hand, while inhibiting irrelevant or intrusive thoughts (Miyake & Shah, 1999). Jha et al. (2010) demonstrated that working memory decreased during a high-stress situation (i.e., military pre-deployment). However, individuals who received mindfulness training, and extensively practiced, did not show this drop in working memory. They also experienced less severe negative affect.

3. Mindfulness and test anxiety

The benefits of mindfulness may also extend to stressful academic settings. High-stakes testing situations are known to increase worries and negative ruminations (DeCaro, Rotar, Kendra, & Beilock, 2010). Moreover, test anxiety is associated with lower academic performance at every educational level (Chapell et al., 2005; Hembree, 1988; Seipp, 1991) and can be viewed as a form of emotion dysregulation that contributes to increased worries and negative self-criticism (Cassady & Johnson, 2002; Cunha & Paiva, 2012). Negative cognitions, like worries and self-doubt, are thought to consume working memory resources needed for optimal test performance (Ashcraft, 2002; Ashcraft & Kirk, 2001; Wine, 1971). We propose that mindfulness may benefit performance in high-stakes academic situations by allowing students to devote greater attention to the test, rather than to negative anxieties that consume valuable working memory resources.

Initial support for this idea comes from two sources. First, a few studies have demonstrated that greater mindfulness is associated with less test anxiety (Cunha & Paiva, 2012; Napoli et al., 2005). Second, mindfulness is associated with better performance in testing situations where performance pressure stems from stereotype threat. For example, Weger, Hooper, Meier, and Hopthrow (2012) found that a brief mindfulness intervention boosted women's math performance when a negative stereotype that "men are better at math" was activated. There was no relationship between mindfulness and math performance when the stereotype was not activated. Thus, mindfulness was most helpful in the threatening situation. Other authors have also separately suggested that the benefits of mindfulness are most visible in stressful situations, with individuals who are highly anxious, and on tests that require greater working memory resources (Brunye et al., 2013; Creswell & Lindsay, 2014). However, the overall relationship linking mindfulness and anxiety to academic performance has not been tested.

4. Current studies

We tested these associations in the current study, examining whether the impact of dispositional mindfulness on high-stakes math performance is mediated by reduced anxiety. We predicted that greater dispositional mindfulness would be associated with less anxiety under pressure and better math performance. The effects of individual differences in mindfulness should be less evident in situations that present low demands on participants' working memory (Study 1) or in low-stakes performance situations (Study 2).

In Study 1, we examined these ideas in a high-stakes testing situation simulated in the laboratory. In Study 2, we extended our investigation to the classroom, examining performance in an undergraduate engineering calculus course.

Mindfulness may be especially important in the engineering context, because engineering students frequently experience anxiety related to their coursework that can impair their attention and memory (Vitasari, Wahab, Herawan, Othman, & Sinnadurai, 2011). We examined their performance on exams, quizzes, and homework assignments completed as part of the course. We considered all of these assignments to be working memory-demanding. However, exams accounted for 75% of students' final grade in the course, and had to be completed in a testing room without notes or books, so these should be especially stressful (i.e., high stakes) and working memory demanding. Thus, we expected to see the greatest impact of mindfulness emerge during exams.

Performance on academic exams and standardized tests (e.g., Scholastic Aptitude Test [SAT], Graduate Record Exam [GRE]) impacts educational retention and determines entry into degree-granting institutions, greatly affecting students' lives. Indeed, poor performance in STEM (Science, Technology, Engineering, and Mathematics) courses, which characteristically use high-stakes testing situations to assess student learning, is a primary reason for student attrition in STEM disciplines such as engineering and math (Geisinger & Raman, 2013). Thus, identifying factors that could facilitate emotion regulation and cognitive control during stressful academic performance situations is of great practical and theoretical importance. The current studies contribute to our knowledge of performance in high-stakes situations by helping to uncover how mindfulness benefits academic performance in anxiety-prone testing situations.

5. Study 1

Study 1 tested the relationship between dispositional mindfulness and state anxiety, and subsequent math performance, in a high-pressure testing situation in a controlled laboratory environment.

5.1. Method

5.1.1. Participants

Participants were undergraduate students ($N = 112$) from the psychology participant pool who were unfamiliar with modular arithmetic (M age = 20.05 years, $SD = 3.97$; 69.6% female). Additional participants were tested, but excluded from the study, for two reasons: (a) reporting that they did not believe the cover story designed to create a high-pressure situation ($n = 11$), or (b) scoring at or below 50% on either the low-demand or high-demand modular arithmetic problems in the practice block ($n = 6$). This minimum accuracy criterion was included to ensure that participants sufficiently understood the modular arithmetic task prior to the high-pressure manipulation. One additional participant's data was identified and removed as a univariate outlier in the regression analyses. The majority of participants identified themselves as white (71.4%), with the remaining individuals identifying themselves as black (9.9%), Asian (5.5%), Hispanic or Latino (3.3%), other (2.2%), or not reported (7.7%).

5.1.2. Modular arithmetic

We assessed math performance with a task widely-used in previous research examining performance under pressure: modular arithmetic (e.g., Beilock & Carr, 2005; Beilock, Kulp, Holt, & Carr, 2004; DeCaro et al., 2010). The modular arithmetic task uses standard operations (i.e., subtraction and division), but presents them in a novel way. Participants were asked to judge the truth value of equations such as "19 = 4 (mod 5)." To solve this equation, participants subtract the second number from the first number (i.e., 19 – 4), which yields "15." Next, they must divide this difference by the "mod" number (i.e., $15 \div 5 = 3$). Finally, they determine whether the answer is evenly divisible by the "mod" number. In this example, the equation "19 = 4 (mod 5)" is "true," because 15 is evenly divisible by the mod "5." The statement is "false" if there is a remainder. Participants solved each of these problems without using a calculator or paper.

To ensure that participants understood the modular arithmetic task, we first instructed them on the rules and then asked them to solve 12 problems in random order with corrective feedback. Then participants completed 24 practice problems in random order without feedback. Finally, participants completed 24 randomized problems under high pressure (as described below). Half of the problems required a single-digit subtraction operation (e.g., 7 = 2 (mod 5)), and thus did not require a borrow operation in the subtraction step. Thus, these items demanded fewer working memory resources to complete (*low-demand problems*). The other half were *high-demand problems* that required subtracting double-digit numbers with a borrow operation (e.g., 63 = 27 (mod 9)), requiring greater working memory resources (Beilock et al., 2004).

5.1.3. Pressure manipulation

To create a high-stakes testing situation in the laboratory, participants were given two pressure-inducing incentives used in previous research: performance-based payment and peer pressure (e.g., Beilock & Carr, 2005; Beilock et al., 2004; DeCaro, Thomas, Albert, & Beilock, 2011). The experimenter explained that the computer had been tracking the participant's performance as he or she solved the initial block of modular arithmetic problems and that the participant needed to improve both problem-solving speed and accuracy by 20% in order to earn $10. Participants were also told that the study also included an element of teamwork, which required both the participant and a "partner" to improve their scores to earn the money. The experimenter noted that the partner had already completed the experiment and did improve by 20%, meaning that earning the reward was entirely contingent upon the present participant meeting the standard. Participants were told that, if they failed to improve by 20%, neither they nor their partner would receive the money. At the end of the study, participants were debriefed and told that the partner was actually fictitious, and were given the $10 regardless of performance.

5.1.4. Audio recordings

In two conditions, participants listened to one of two 15-min audio recordings (mindful breathing [$n = 41$] or progressive muscle relaxation [$n = 38$]; Feldman, Greeson, & Senville, 2010). However, these manipulations did not impact any dependent measures, including ratings of pressure, state mindfulness, state anxiety, or modular arithmetic performance, compared to a control condition ($n = 33$) in which no audio recording was used, Fs < 1. Thus, the audio recording variable was not included in final analyses and will not be described further.

5.1.5. Self-report measures

5.1.5.1. Mindfulness. The Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003) was used to assess dispositional mindfulness. The MAAS is a widely-used measure, and includes 15 items (e.g., "I find it difficult to stay focused on what's happening in the present"; "I find myself preoccupied with the future or the past") that are rated on a Likert-type scale of one ("almost always") to six ("almost never") (Cronbach's $\alpha = .84$). Scores are computed by averaging the 15 items. Higher scores indicate higher levels of dispositional mindfulness.

The Toronto Mindfulness Scale – Trait (TMS-T; Davis, Lau, & Cairns, 2009) was also administered to assess two specific characteristics of dispositional mindfulness: curiosity (6 items; $\alpha = .81$) and decentering (7 items; $\alpha = .63$). However, no significant relationship between these factors and the primary measures of interest were found (i.e., STAI and math accuracy, controlling for gender; curiosity: STAI $r = -.026$, $p = .788$, low-demand math accuracy $r = -.061$, $p = .522$, high-demand math accuracy $r = -.062$, $p = .521$; decentering: STAI $r = -.150$, $p = .116$, low-demand math accuracy $r = .003$, $p = .978$, high-demand math accuracy $r = -.116$, $p = .225$). Curiosity items were also not significantly correlated with MAAS scores, $r = -.112$, $p = .240$. However, decentering items were significantly negatively correlated with the MAAS, $r = -.255$, $p = .007$. This finding is opposite that of previous research, which shows a positive correlation between decentering scores and the MAAS (Davis et al., 2009). For these reasons, and because the MAAS is more general and standardly used (Bergomi, Tschacer, & Kupper, 2007; Quaglia, Brown, Lindsay, Creswell, & Goodman, 2015), we selected the MAAS as our measure of dispositional mindfulness.

The Toronto Mindfulness Scale – State (TMS-S; Lau et al., 2006) was used to examine differences in state mindfulness as a result of the audio recordings. This scale also includes curiosity (6 items; $\alpha = .85$) and decentering (7 items; $\alpha = .66$) factors.

5.1.5.2. State anxiety. Participants completed the state version of the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, & Lushene, 1970) to assess state anxiety as a result of the pressure manipulation. The STAI includes 20 items (e.g., "I feel nervous"; "I am presently worrying over possible misfortunes") that are rated on a Likert-type scale of one ("not at all") to four ("very much so") ($\alpha = .91$). After reverse-coding some items, items are summed to create a total score. Higher scores indicate higher levels of anxiety.

5.1.5.3. Post-experiment questionnaires. Individuals rated how important it was to them to perform at a high level on the last set of math problems on a Likert-type scale of one ("not at all important") to seven ("extremely important"). Also, individuals rated how much pressure they felt to perform at a high level on a Likert-type scale of one ("very little performance pressure") to seven ("extreme performance pressure"). They were asked to briefly explain their responses to each of these items in an open-response format. Finally, participants completed a questionnaire to report demographic information.

5.1.6. Procedure

All participants completed the dispositional mindfulness questionnaires (i.e., MAAS, TMS-T) and then received instructions on how to solve modular arithmetic problems followed by the practice problems. Then, either immediately or following the audio recordings (see above), participants were told the cover story to induce a high-pressure situation and asked to complete an additional set of modular arithmetic problems. Next, all participants completed an unrelated task[1] for approximately 5 min, followed by the TMS-State, STAI, and post-experiment questionnaires. Finally, participants were debriefed.

5.2. Results and discussion

We hypothesized that, in a high-stakes situation, trait mindfulness would indirectly benefit math accuracy by reducing state anxiety. We specifically expected this pattern of findings for high-demand problems, which most depend on working memory (Beilock et al., 2004).

To control for possible speed-accuracy trade-offs in participants' problem-solving performance, we included low-demand or high-demand problem reaction times as covariates in all analyses for low-demand or high-demand accuracy, respectively.

[1] Following the math task, participants completed an Emotional Stroop task as an exploratory measure. Because this task was not directly related to the current research question, and no significant findings were revealed, we do not discuss this task further.

These trade-offs were unlikely, however, as reaction time did not predict either low-demand ($\beta = -.04$, $t(110) = -0.38$, $p = .703$) or high-demand ($\beta = .10$, $t(110) = 1.04$, $p = .303$) problem accuracy.

Preliminary analyses indicated that gender significantly predicted high-demand problem accuracy ($\beta = -.22$, $t(109) = -2.29$, $p = .024$, $R^2 = .055$; effects coded: male = −1, female = 1), with women performing at a lower level than men. Gender did not predict low-demand problem accuracy ($\beta = -.03$, $t(109) = -0.28$, $p = .778$). This finding is consistent with extensive research demonstrating the impact of gender-related stereotypes about math on working memory-demanding problems (Beilock, Rydell, & McConnell, 2007; Schmader & Johns, 2003) and in high-stakes testing situations (see Schmader, 2010). Gender did not interact with mindfulness ($\beta = -.09$, $t(107) = -0.86$, $p = .391$). Thus, gender was also included as a covariate in all analyses, to examine the relationships between the predicted factors beyond any impact of gender.

We began by conducting separate regression analyses to examine the relationships between each of the variables in the model. Covariates were entered as Step 1, followed by the predictor variable of interest in Step 2 (ΔR^2). Table 1 presents descriptive statistics for these variables. As shown in Fig. 1a, for high-demand problems, greater mindfulness was associated with significantly better math accuracy ($\beta = .20$, $t(108) = 2.19$, $p = .031$, $\Delta R^2 = .040$, Total $R^2 = .095$) and significantly lower state anxiety scores ($\beta = -.29$, $t(108) = -3.25$, $p = .002$, $\Delta R^2 = .083$, Total $R^2 = .155$). In addition, lower state anxiety scores were associated with higher math accuracy ($\beta = -.25$, $t(108) = -2.62$, $p = .010$, $\Delta R^2 = .057$, Total $R^2 = .112$). In contrast, for low-demand problems (Fig. 1b), mindfulness ($\beta = .05$, $t(108) = 0.54$, $p = .590$, $\Delta R^2 = .003$, Total $R^2 = .005$) and state anxiety scores ($\beta = -.19$, $t(108) = -1.94$, $p = .055$, $\Delta R^2 = .034$, Total $R^2 = .036$) did not predict math accuracy.

We used the method described by Hayes (2009, 2013) to test our predicted mediation model, in which the effect of mindfulness on math accuracy is mediated by state anxiety. A bias-corrected 95% confidence interval (CI) for this indirect effect was calculated using 10,000 bootstrap samples. Mediation is said to be present if the CI for the indirect effect does not include zero (Shrout & Bolger, 2002). Scores were standardized before inclusion in the model. As expected, there was a significant indirect effect of mindfulness on high-demand math accuracy through the mediator, state anxiety ($\beta = .06$, CI [.010,.140]; Fig. 1a). The direct effect was not significant, indicating that trait mindfulness did not influence high-demand problem accuracy independent of its effect on state anxiety ($\beta = .14$, $t(107) = 1.51$, $p = .135$). The full model accounted for 13.0% of the variability in high-demand problem accuracy. There were no significant indirect ($\beta = .06$, CI[−.005,.173]) or direct ($\beta = -.004$, $t(107) = -.04$, $p = .965$) effects of mindfulness on low-demand problem accuracy (Fig. 1b).

Thus, Study 1 provides support for a mediation model whereby dispositional mindfulness reduces state anxiety in a high-pressure testing situation, indirectly improving math accuracy. The effect of mindfulness was selective to problems that place a high demand on working memory. These findings are consistent with others demonstrating that high-pressure situations disrupt the working memory needed to solve high-demand problems (e.g., Beilock et al., 2004; DeCaro et al., 2010). Moreover, these findings suggest that dispositional mindfulness can reduce the anxiety experienced in a high-stakes testing situation, freeing the working memory resources needed for optimal performance.

6. Study 2

Study 1 supported the proposed mediation model in a controlled laboratory setting. Study 2 was designed to test this model in a more ecologically-valid context, an undergraduate engineering mathematics course. Study 2 also extended the model to general perceptions of anxiety toward course test-taking (i.e., test anxiety). In addition, because the course included both low-stakes (i.e., homework assignments) and high-stakes (i.e., quizzes and exams) performance measures, we were able to examine the selective impact of mindfulness on these types of assignments. We predicted that dispositional mindfulness would indirectly benefit performance by reducing test anxiety, specifically for assignments with higher stakes (quizzes and exams), but not for assignments with lower stakes (homework).

6.1. Method

6.1.1. Participants

Participants ($N = 248$; 24% female) were first-time, full-time freshman undergraduate engineering students enrolled in a calculus course who gave consent to be in the study. Data from two participants were found to be univariate outliers and were removed from the dataset. The majority of participants identified themselves as white (90%), with the remaining individuals identifying themselves as Asian (2.8%), black (1.6%), Hispanic or Latino (1.6%), or two or more races or unreported (4%). Consistent with prior research, three measures of prior mathematics and science ability were collected as indicators of prior knowledge: standardized college entrance examination scores (ACT-Math [American College Test]; $M = 30.62$, $SD = 2.52$; ACT-Science; $M = 29.90$, $SD = 3.33$), and a department-validated Algebra Readiness Examination score ($M = 75.2\%$, $SD = 16.6\%$; Hieb, Lyle, Ralston, & Chariker, 2015).

6.1.2. Self-report measures

The current research questions were examined as part of a larger, ongoing study examining the performance and retention of first-year engineering students. Two questionnaires were relevant to the current study: the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003; $\alpha = .87$; see Study 1 for details) and the Cognitive Test Anxiety Scale (CTAS; Cassady, 2004; Cassady & Johnson, 2002). The CTAS measures the cognitive dimension of test anxiety, including the presence

Table 1
Descriptive statistics for Study 1.

	Mean	*SD*
Dispositional mindfulness (MAAS)	3.69	0.68
State anxiety (STAI)	38.78	10.29
High-demand problem accuracy (%)	78.72	14.71
Low-demand problem accuracy (%)	96.50	5.66
High-demand problem RT (ms)	9223.20	4113.13
Low-demand problem RT (ms)	2261.39	838.28

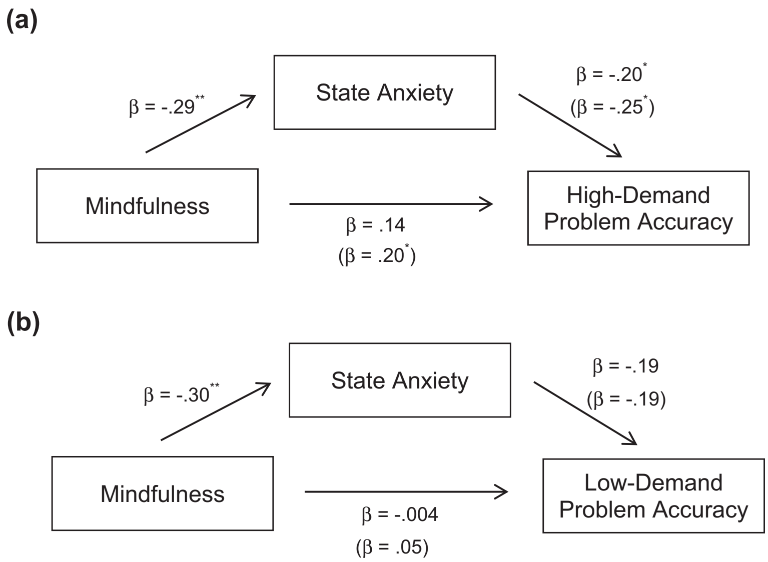

Fig. 1. Relationships among factors in the mediation models predicting (a) high-demand problem accuracy and (b) low-demand problem accuracy. Note: Values in parentheses represent zero-order regression coefficients. Values outside parentheses represent regression coefficients when all variables are included in the mediation model. Gender and reaction time (not shown) are included as covariates in all analyses. $^{*}p < .05$, $^{**}p < .01$.

of task-irrelevant and intruding thoughts, inattention to relevant information, and comparing one's self to others. The CTAS ($\alpha = .93$) includes 27 items (e.g., "I lose sleep over worrying about examinations"; "When I take a test, my nervousness causes me to make careless errors") that are rated on a Likert-type scale of one ("not at all typical of me") to four ("very typical of me"). Students were asked to respond to this scale with respect to their math class. Scores are computed by summing responses to all items. Higher scores indicate greater cognitive test anxiety.

6.1.3. Academic performance

Students' course grades were comprised of the Algebra Readiness Exam (5%), 15 homework assignments (5%), 11 quizzes (15%), and 14 exams (75%). Importantly, all quizzes and exams were completed without external aides, including books, notes, and calculators. As specified in the course syllabus, each student was allowed to drop their lowest quiz and exam scores (excluding the last three exams). After removing the lowest quiz and exam scores, average homework, quiz, and exam scores were calculated for each student to create three course outcome measures.

6.1.4. Procedure

The Algebra Readiness Exam was administered to all students during the first week of the course as part of the course requirements. Students completed the self-report questionnaires on a computer during class, approximately mid-semester. After the semester, academic and demographic information were connected to survey responses by a third party, and all identifying information was removed from the data.

6.2. Results and discussion

We hypothesized that trait mindfulness would benefit grades through an association with reduced trait test anxiety, and this effect would emerge specifically for high-stakes assignments (quizzes and exams).

ACT-Math, ACT-Science, and Algebra Readiness Exam scores were included as covariates for all analyses, to control for prior ability. These scores were positive predictors of course exam and quiz scores (βs = .18–.49, ps < .001–.004, R^2s = .033–.239), but not homework scores (βs = −.07 to .02, ps = .259–.719, R^2s = .001–.005).

Preliminary analyses revealed a significant relationship between gender and performance on exams ($\beta = .22$, $t(243) = 3.91$, $p < .001$), quizzes ($\beta = .14$, $t(243) = 2.65$, $p = .008$), and homework ($\beta = .13$, $t(243) = 2.05$, $p = .041$). In contrast to Study 1, females scored at a higher level than males (effects coded: males = −1, females = 1). These findings are interesting in light of research demonstrating the impact of negative stereotypes for women in STEM (Schmader & Johns, 2003), who were a minority of students (24%) in this course. These findings are, however, consistent with the idea that women who have successfully entered as minorities in engineering may be less impacted by negative stereotypes, at least as measured by grades (e.g., Crisp, Bache, & Maitner, 2009; Regner et al., 2010). Gender did not interact with mindfulness to predict any of the dependent measures (βs = −.004 to −.06, ps = .415–.949). We included gender as a covariate in all analyses to determine the impact of mindfulness and anxiety beyond any effect of gender.

We first examined the separate relationships between the variables in the model. Descriptive statistics for these variables are reported in Table 2. The covariates were entered as Step 1 in all analyses, followed by the predictor variable of interest in Step 2 (ΔR^2). As shown in Fig. 2a, mindfulness positively predicted exam scores ($\beta = .11$, $t(242) = 2.00$, $p = .047$, $\Delta R^2 = .012$, Total $R^2 = .287$) and negatively predicted cognitive test anxiety ($\beta = -.39$, $t(242) = -6.95$, $p < .001$, $\Delta R^2 = .143$, Total $R^2 = .285$). Cognitive test anxiety also negatively predicted exam scores ($\beta = -.21$, $t(242) = -3.60$, $p < .001$, $\Delta R^2 = .037$, Total $R^2 = .312$). As shown in Fig. 2b, mindfulness did not significantly predict quiz scores ($\beta = .05$, $t(242) = 1.01$, $p = .312$, $\Delta R^2 = .003$, Total $R^2 = .342$), but greater cognitive test anxiety was associated with lower quiz scores ($\beta = -.23$, $t(242) = -4.14$, $p < .001$, $\Delta R^2 = .044$, Total $R^2 = .383$). Finally, as shown in Fig. 2c, neither mindfulness ($\beta = .03$, $t(242) = 0.45$, $p = .650$, $\Delta R^2 = .001$, Total $R^2 = .025$) nor cognitive test anxiety ($\beta = .06$, $t(242) = 0.87$, $p = .387$, $\Delta R^2 = .003$, Total $R^2 = .027$) predicted homework scores.

We tested our predicted mediation model for average exam, quiz, and homework scores separately, using Hayes's (2009, 2013) method as in Study 1. As shown in Fig. 2a, there was a significant indirect effect of mindfulness on exam scores through the mediator cognitive test anxiety ($\beta = .07$, BC bootstrap 95% CI[.026,.133]). There was no significant direct effect of mindfulness on exam performance ($\beta = .04$, $t(241) = .62$, $p = .537$), indicating that mindfulness did not influence exam scores independent of its effect on cognitive test anxiety. The full model accounted for 31.4% of the variability in average exam scores.

As shown in Fig. 2b, there was also a significant indirect effect of mindfulness on quiz scores ($\beta = .09$, BC bootstrap 95% CI [.046,.155]), and no direct effect ($\beta = -.04$, $t(241) = -.70$, $p = .483$). Similar to the exam results, this finding indicates that mindfulness influenced quiz scores indirectly through an association with reduced cognitive test anxiety. The full model accounted for 38.4% of the variability in average quiz scores.

For homework scores (Fig. 2c), no indirect ($\beta = -.03$, BC bootstrap 95% CI[−.090,.011]) or direct effects ($\beta = .06$, $t(241) = .89$, $p = .377$) of mindfulness were found.

These findings again support the predicted mediation model. In an undergraduate engineering mathematics course, higher dispositional mindfulness was associated with better exam grades. This effect was statistically mediated by cognitive test anxiety, measured as a dispositional attitude about test-taking in the course. The indirect effect of mindfulness on grades was present for both exams and quizzes, but not for homework assignments, indicating that mindfulness is most likely associated with benefits in higher-stakes testing situations.

7. General discussion

Across two studies, we found support for the hypothesis that mindfulness benefits math performance by reducing anxiety associated with high-stakes testing conditions. In Study 1, undergraduate students were given a high-pressure scenario in the laboratory prior to completing novel math problems. Greater dispositional mindfulness was associated with lower levels of reported anxiety after the math test. In turn, lower anxiety was associated with better scores on high-demand problems that taxed working memory by requiring multiple mental calculations. Neither state anxiety nor mindfulness predicted performance on less demanding problems.

Previous research has demonstrated that high-pressure testing situations increase worries and negative thoughts, selectively impairing performance on working memory-demanding problems (e.g., Beilock et al., 2004; DeCaro et al., 2010). In the current study, mindfulness was associated with reduced anxiety and improved high-demand problem accuracy. These findings are consistent with the idea that mindfulness buffers individuals against the negative impact of worries and intrusive thoughts, protecting working memory resources (e.g., Jha et al., 2010) so that individuals can devote these resources to solving more difficult math problems.

Study 2 replicated and extended these findings in a university classroom. Engineering students enrolled in calculus, a gateway course for the major, reported both their dispositional mindfulness and cognitive test anxiety, a dispositional measure that reflects cognitive reactions (e.g., worries and intrusive thoughts) toward test-taking. These measures were examined in relation to three course components that varied in the stakes associated with performance: exams, quizzes, and homework. Both exams and quizzes were completed in a traditional testing context, without the assistance of a calculator, books, or course notes. Exams and quizzes were considered high-stakes, because they accounted for 75% and 15% of the students' course grades respectively. In contrast, homework assignments (5% of the course grade) were considered low-stakes.

Table 2
Descriptive statistics for Study 2.

	Mean	*SD*
Dispositional mindfulness (MAAS)	3.85	0.78
Trait cognitive test anxiety (CTAS)	62.81	15.43
Average exam score (%)	73.87	12.44
Average quiz score (%)	74.07	12.09
Average homework score (%)	95.44	9.45

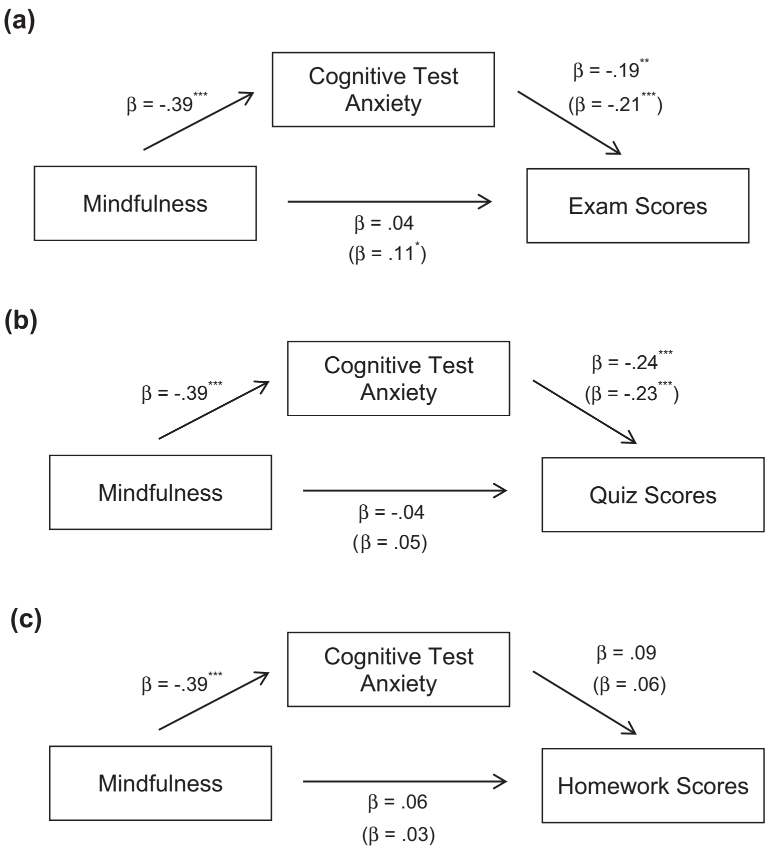

Fig. 2. Relationships among factors in the mediation models predicting average (a) exam scores, (b) quiz scores, and (c) homework scores. Note: Values in parentheses represent zero-order regression coefficients. Values outside parentheses represent regression coefficients when all variables are included in the mediation model. Gender, ACT-Math, ACT-Science, and Algebra Readiness Exam scores (not shown) are included as covariates in all analyses. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

All course material was likely working memory-demanding, given the topic (calculus), although working memory demand was not explicitly investigated in this study. Higher dispositional mindfulness was associated with lower dispositional cognitive test anxiety, which in turn benefited students' high-stakes exam and quiz performance. Mindfulness was not associated with performance on lower-stakes homework performance.

The results of Studies 1 and 2 reveal an important mechanism by which mindfulness may benefit learning and performance. Mindfulness appears to reduce anxious thoughts that otherwise consume working memory resources. Thus, the immediate benefits of mindfulness for performance may be most pronounced when the task requires significant working memory resources to complete. These positive effects of mindfulness may be especially evident in contexts in which anxious thoughts can impinge on working memory resources, as in high-stakes testing situations (Beilock & Carr, 2005; Beilock & DeCaro, 2007; Beilock et al., 2004; see also Creswell & Lindsay, 2014).

More work is needed to further substantiate the link to working memory, however, as working memory was manipulated only in Study 1. One way to do this may be to measure individual differences in working memory capacity. Beilock and Carr (2005; see also Beilock & DeCaro, 2007) demonstrated that the performance of individuals with higher working memory capacity was most impacted by performance pressure. Pressure appears to co-opt the working memory resources these individuals rely on for their typically superior performance. The link between mindfulness, anxiety, and academic performance might therefore be strongest for individuals with higher working memory capacity.

These findings contribute to the growing literature on mindfulness in academic settings. Mindfulness may benefit cognitive or self-regulation abilities that support academic performance more generally, although research on the connection of these improvements to educational outcomes is limited (Shapiro et al., 2011). Research has demonstrated that mindfulness reduces mind wandering, improving performance on reading comprehension tests such as those found on the Graduate Record Exam (GRE; Mrazek et al., 2013). We demonstrate a different mechanism by which mindfulness may benefit academic performance. Mindfulness may allow students to remain focused on the task in anxiety-producing testing situations. Thus, students with greater mindfulness may be better able to thrive in important testing situations that might otherwise lead to underperformance.

This work provides promising initial support for the benefit of mindfulness in academic testing situations. However, these findings are correlational, based on self-report measures of mindfulness and anxiety. Future research is needed to test the causal link between mindfulness and high-stakes test performance more directly by examining the effect of mindfulness training interventions on anxiety reduction and test performance. Mindfulness interventions have been successfully implemented in educational contexts, improving emotional functioning and cognitive performance (Zenner et al., 2014). However, the brief mindfulness intervention used in our Study 1 did not reduce anxiety or improve performance. This finding corresponds with other work demonstrating that more extensive mindfulness practice is associated with greater treatment effects (Zenner et al., 2014). By specifically targeting attention control and decentering from anxious thoughts, mindfulness training may be an especially useful method for reducing the impact of test anxiety and pressure felt in high-stakes testing situations.

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