Learning and Individual Differences 27 (2013) 1–7

Contents lists available at ScienceDirect

Learning and Individual Differences

journal homepage: www.elsevier.com/locate/lindif

Learning to relax: Evaluating four brief interventions for overcoming the negative emotions accompanying math anxiety

Tad T. Brunyé [a,b,*], Caroline R. Mahoney [a,b], Grace E. Giles [a,b], David N. Rapp [c], Holly A. Taylor [a], Robin B. Kanarek [a]

[a] Tufts University, Department of Psychology, Medford, MA, United States
[b] U.S. Army NSRDEC, Cognitive Science, Natick, MA, United States
[c] Northwestern University, School of Education and Social Policy & Department of Psychology, Evanston, IL, United States

ARTICLE INFO

Article history:
Received 23 August 2012
Received in revised form 26 April 2013
Accepted 20 June 2013

Keywords:
Math anxiety
Mindfulness
L-theanine
Focused breathing
Executive control

ABSTRACT

We examined the potential effectiveness of four brief interventions, three behavioral and one nutritional, for helping high math-anxious college students regulate negative emotions immediately prior to a time-pressured arithmetic test. Participants with low versus high math anxiety performed a timed arithmetic task after practicing one of three short-term breathing exercises promoting focused attention, unfocused attention, or worry, and after consuming either 0 or 200 mg L-theanine. Overall, participants with high math anxiety underperformed relative to those with low math anxiety. This effect, however, was largely alleviated by a focused breathing exercise, which increased rated calmness and enhanced performance on the arithmetic test amongst those with high math anxiety. L-theanine supplementation showed only minimal effects. These results provide insights into the attentional mechanisms involved in regulating the negative emotions that lead to testing underperformance, and suggest that focused breathing exercises can be a useful, practical tool for helping address the negative impacts of math anxiety.

Published by Elsevier Inc.

1. Introduction

Individual differences in math anxiety cause many intellectually capable students to opt out of higher mathematics education, ultimately decreasing enrollment in mathematics courses and reducing work force competencies (for a review, see Ashcraft, 2002). Identifying reliable and tractable therapeutic methods for reducing the negative emotions accompanying math anxiety is critical to increasing student participation in higher mathematics education, increasing mathematics competencies, and supporting math-related career decisions in science, technology, engineering, and mathematics (STEM) disciplines (Ashcraft & Krause, 2007). To this end, we examined the effects of four brief interventions, three behavioral mindfulness interventions (focused breathing, unfocused breathing, versus a worry exercise) and one nutritional intervention (L-theanine supplementation), on reducing negative emotions and boosting math testing performance in individuals with low versus high levels of math anxiety.

1.1. Math anxiety

An estimated majority (Perry, 2004) of college students exhibit math anxiety, characterized by feelings of fear and tension in anticipation of situations demanding the application of mathematics knowledge (Ashcraft, 2002). Students with high math anxiety avoid math exposure in both daily life (e.g., calculating a tip at a restaurant) and formal educational coursework (e.g., calculus), ultimately resulting in lower exposure to math, reduced practice using mathematics principles, and reduced workforce math competence. Because time-pressured testing situations characterize many college mathematics courses, math anxiety becomes a primary impediment to students' academic success.

Individual differences in the ability to effectively control attention during testing (often measured via working memory capacity; Engle, 2002) predict speed and accuracy during arithmetic problem solving (Geary & Widaman, 1992). Behavioral and cognitive neuroscience results suggest that regulating emotions, and specifically regulating feelings of anxiety, demands resources in the very same brain networks critical to effectively controlling attention (for a review, see Ochsner & Gross, 2005). Together, this work predicts that high math-anxious students devote a considerable amount of cognitive and attentional resources towards intrusive thoughts and worries, rather than the processing demands of the arithmetic task, resulting in underperformance (Ashcraft, 2002; Beilock & Carr, 2005). Evidence for this relationship comes from studies demonstrating high math-anxious students begin to underperform only when, 1) tests are given in time-pressured circumstances (Faust, Ashcraft, & Fleck, 1996), and 2) arithmetic problems become more complex and demand increasingly high working memory resources for processes such as carrying, borrowing, and monitoring and updating sequences of operations (Ashcraft & Krause, 2007).

* Corresponding author at: Tufts University, Department of Psychology, 490 Boston Ave, Medford, MA 02155, United States. Tel.: +1 617 627 4075.
E-mail address: tbruny01@tufts.edu (T.T. Brunyé).

1041-6080/$ – see front matter. Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.lindif.2013.06.008

If math anxious college students generally have the knowledge and ability to perform mathematics operations but are limited in their ability to effortfully control attention during anxiety-inducing situations, then treatments targeted at reducing anxiety and training attentional control might prove beneficial in supporting their math test performance. Unfortunately many contemporary treatments for math anxiety tend to be costly, rare, instructor-driven, and can require long-term (e.g., 2–14 weeks) commitments by students (often resulting in attrition). Recent work has identified one successful short-term intervention, asking students to briefly write about their testing worries immediately prior to a math exam. This activity provides temporary relief of the "burden that worry places on working memory," ultimately boosting math test scores by 5–10% (Ramirez & Beilock, 2011, p. 211). With the goal of building a resource toolkit of short-term interventions which students and instructors alike can easily implement, we investigated mindfulness-based and nutrition-based approaches that might prove valuable in reducing math anxiety and freeing up the mental resources necessary for performance during high pressure tests.

1.2. Focused breathing and attentional control

Attentional control theory (Eysenck, Santos, Derekeshan, & Calvo, 2007) suggests that when individuals experience anxiety about upcoming events they show impairments in effortfully controlling attention in a goal-directed manner. Under this theory, states of anxiety cause cognitive resources to be diverted away from task-relevant stimuli (e.g., math test performance) towards worry and rumination. A result of this resource shift is impairment of cognitive processes necessary for maintaining performance on difficult tasks, for instance controlling and shifting attentional resources, and updating and monitoring the contents of working memory (cf., Miyake et al., 2000). Attentional control theory provides a solid foundation for understanding why the math anxious show reduced test performance in spite of having the requisite knowledge to solve a task. Indeed as arithmetic problems become more demanding of carrying and borrowing operations, they recruit executive resources towards updating and monitoring (Hitch, 1978; Logie, Gilhooly, & Wynn, 1994). If these resources are otherwise consumed by anxious worry, cognitive performance suffers. The theory also makes the strong suggestion that some practices, such as mindfulness-based exercises aimed at reducing anxiety, hold potential in freeing up the mental resources necessary for controlling attention during demanding arithmetic tasks.

Mindfulness describes a mental state that allows individuals to maintain full attention to the sensations of present, ongoing experience. Long-term mindfulness training, such as mindfulness-based stress reduction (MBSR), has proven beneficial in promoting regulatory mental functioning such as controlling attention and regulating emotions (Lutz, Brefczynski-Lewis, Johnstone, & Davidson, 2008). Beneficial effects of mindfulness practices have also been found following relatively short-term bouts of focused breathing. For instance, 20 min of focused breathing enhances focused attention on the Stroop task (Wenk-Sormaz, 2005) and performance on a visuospatial task requiring attentional control (Kozhevnikov, Louchakova, Josipovic, & Motes, 2009). Behavioral evidence for the effects of mindfulness training on the control of attention is complemented by emerging findings in cognitive neuroscience (for a review, see Lutz et al., 2008). Brief bouts of mindfulness exercises (such as focused breathing) may hold promise for reducing anxious worry and enhancing test performance immediately following a short-term exercise; if this is the case, this type of exercise might prove advantageous in classroom settings involving high-stakes testing.

1.3. L-theanine and attentional control

The consumption of teas containing the amino acid L-theanine is historically associated with relaxing properties and may hold promise as a mild anxiolytic (Juneja, Chu, Okubo, Nagato, & Yokogoshi, 1999). Gomez-Ramirez et al. (2007) measured electroencephalographic (EEG) response during rest and after 250 mg of L-theanine, and found L-theanine related increased anticipatory alpha band activity over parietal and occipital scalp regions, suggesting reduced arousal states and potentially enhanced effortful control of attention.

To our knowledge very few studies have investigated L-theanine effects on acute stress response in humans, and results are equivocal. Kimura, Ozeki, Juneja, and Ohira (2007) suggest that 200 mg L-theanine supplementation can reduce both psychological and physiological stress responses to a mental arithmetic task (see also, Haskell, Kennedy, Milne, Wesnes, & Scholey, 2008). In contrast, Rogers, Smith, Heatherley, & Pleydell-Pearce, 2008 showed 200 mg of L-theanine reduced blood pressure relative to placebo, but did not reduce anxiety or arousal ratings. Similar results were found by Lu et al. (2004), who found that L-theanine did not reduce anxiety levels relative to placebo under stressful conditions. Thus, current results are mixed with regard to L-theanine's effects on human affective state and performance under anxiety-provoking circumstances.

1.4. The present study & hypotheses

To examine the effects of mindfulness exercises and L-theanine supplementation, we administered either 0 or 200 mg of L-theanine in capsule form, crossed with one of three breathing exercises (focused, unfocused, worry), in a repeated-measures design. Participants then completed a timed arithmetic task designed to elicit acute stress. We hypothesized that: 1) Students with high versus low math anxiety would show lower math subtest performance on standardized achievement tests, and relatively poor performance on the timed arithmetic task, 2) Students with high versus low math anxiety would show lower working memory capacity, indicating reduced capacity to effortfully control attention during complex timed tasks, 3) Focused breathing (versus unfocused or worry), and L-theanine supplementation (versus placebo), would increase self-reported calmness and decrease nervousness, particularly among those with high math anxiety, 4) The worry condition would induce the lowest overall arithmetic test performance (versus unfocused or focused), particularly among those with high math anxiety, and 5) If focused breathing and/or L-theanine supplementation increase self-reported calmness, these effects would translate to enhanced testing performance in math-anxious students.

2. Method

2.1. Participants

Thirty-six Tufts University undergraduates (18 males, 18 females) participated for monetary compensation. Demographics are detailed in Table 1. All participants were non-tobacco users and were not taking any prescription medications (other than oral contraceptives). Participants were excluded if they: reported being pregnant or nursing, have trouble swallowing pills, or have a history of diabetes, depression, anxiety disorders, panic attacks, cardiac disease, hepatic function impairment, hypertension, peptic ulcer disease, severe reflux or insomnia.

2.2. Design

We used a within-participants design with two independent variables, L-theanine (double-blind; 0 mg, 200 mg), and Breathing (Focused, Unfocused, Worry). These two factors were fully counterbalanced across participants. The two treatment levels were administered in identical capsule form with water; placebo contained microcrystalline cellulose powder.

Table 1
Mean and standard deviation demographic and individual differences measures for all participants, and also the two math anxiety groups (low/high). Statistical results derived from independent-samples t-tests comparing the two math anxiety groups (df = 34), *p < .05.

Demographic	All participants *Mean*; *SD*	Low math anxiety *Mean*; *SD*	High math anxiety *Mean*; *SD*	t-Statistic	Effect size (Cohen's *d*)
Age (years)	20.8; 2.6	21.3; 2.7	20.3; 2.5	1.09	.38
Body Mass Index (BMI)	22.2; 2.9	22.2; 2.1	22.3; 2.6	.12	.04
Tea Consump. (oz/day)	5.7; 9.2	5.9; 7.1	5.5; 11.1	.11	.04
MAAS	4.0; .66	3.9; .63	4.1; .69	.71	.30
FFMQ: Observe	25.9; 4.8	26.6; 4.8	25.4; 4.9	.72	.25
FFMQ: Describe	29.5; 5.9	30.6; 6.5	28.5; 5.2	1.05	.36
FFMQ: Act Aware	26.6; 4.9	25.2; 4.1	27.9; 5.3	1.8	.57
FFMQ: Non Judging	29.3; 6.1	29.9; 6.2	28.6; 6.1	.63	.21
FFMQ: Non Reactive	21.9; 4.8	22.9; 4.5	20.9; 5.1	1.25	.42
OSPAN (# words)	28.8; 12.3	32.8; 10.1	24.7; 13.2	2.1*	.69
SAT Scores: Math	695.8; 86.2	726.7; 65.2	665; 95.1	2.7*	.76
SAT Scores: Verbal	677.4; 85.9	684.4; 78	670.3; 95	.49	.16

3. Materials

3.1. Individual differences measures

To measure individual differences in self-rated math anxiety, we used the widely-administered and validated (Alexander & Cobb, 1987; Rounds & Hendel, 1980) 30-item Mathematics Anxiety Rating Scale (MARS; Suinn & Winston, 2003). This instrument measures self-rated anxiety regarding several real-world arithmetic situations, such as *Being given a pop quiz in a math class*, and *Watching someone work with a calculator*.

To account for potential differences between math anxiety groups in susceptibility to and acceptance of mindfulness-based practices, we administered the Mindful Attention Awareness Scale (MAAS), and the Five Facet Mindfulness Questionnaire (FFMQ). The MAAS has been validated across several samples (e.g., Carlson & Brown, 2005) and asks about day-to-day experiences with dispositional mindfulness, rating the frequency of experiences such as *I find it difficult to stay focused on what's happening in the present*. The FFMQ is widely-administered and validated (e.g., de Bruin, Topper, Muskens, Bögels, & Kamphuis, 2012), and probes dispositional mindfulness by using ratings to items such as *I find myself doing things without paying attention*. The FFMQ is divided into five sub-scales related to: observing sensations, perceptions, thoughts and feelings, describing/labeling with words, acting with awareness, non-judging of experience, and nonreactivity of inner experience.

Finally, to assess working memory capacity we administered the Operation Span (OSPAN), which indexes an individual's ability to maintain information in working memory while also solving simple arithmetic tasks (i.e., under heightened attentional control requirements; Engle, 2002). Overall scores are detailed in Table 1.

3.2. Affective state measure

To assess self-reported psychological state, we used the Brief Mood Introspection Scale (BMIS). The BMIS involves responding based on the extent to which each adjective is representative of present mood.

3.3. Breathing exercises

Three breathing exercises were developed, modeled after Arch and Craske (2006); each exercise was 15 min in duration. In each condition, participants listened to a recording instructing them to establish a straight upright sitting posture, hands resting on their lap, shoulders relaxed, head upright, and feet resting flat on the floor. If comfortable doing so, they were asked to close their eyes; if not, they were asked to direct gaze slightly downward and forward without focusing on anything in particular. The remainder of the exercise differed by condition:

3.3.1. Focused breathing exercise

This exercise was extracted from Kabat-Zinn's (2005) Guided Mindfulness Meditation practice CDs (disc 3, *Sitting Meditation*). In this exercise, participants are guided through instructions and practice opportunities centered around an attentional focus on the sensations of the breath (inhalation and exhalation). For instance, participants are told to "*tune into the feeling of the breath moving in and out of your body, focusing on the sensation of the breath moving past the nostrils; or alternatively, on the feeling of your belly expanding gently on each in-breath, and receding gently with each out-breath.*" Participants are repeatedly encouraged to refocus to the breath if the mind wanders away from its sensations.

3.3.2. Unfocused exercise

Participants were repeatedly instructed to "*simply think about whatever comes to mind. Let your mind wander freely without trying to focus on anything in particular.*" We chose an active rather than passive control exercise in order to unconfound levels of engagement across the three breathing exercises; we further expected that this type of exercise would provide individuals inclined to rumination with the opportunity to think anxiously about the upcoming arithmetic test.

3.3.3. Worry exercise

Participants were asked a series of 15 anxiety-inducing questions (e.g., *what is it about cancer that you would find fearful or bad if it actually did happen to you?*), to answer silently to themselves, "thinking seriously and deeply about each topic. Consider how each topic would relate not only to you, but to your loved ones, such as family and friends." Two versions of the worry task were created, one for each of the two test sessions incorporating this exercise. Topics included personal health (e.g., obesity, depression), environmental issues (e.g., global warming), social issues (e.g., losing friends, discrimination), personal finance (e.g., debt, paying off loans) and international crises (e.g., terrorism, recession).

3.4. Arithmetic task

A mental arithmetic task was adapted from those used by Kimura et al. (2007) and Tang et al. (2007). During the 20-minute task, participants were presented with 300 double-column arithmetic problems that ranged from low (e.g., 10 + 40) to high (e.g., 29 + 47) difficulty, one at a time in the center of the computer monitor. Difficulty was operationalized as whether numbers were divisible by 10, odd versus even, and greater than or less than 19. There were five difficulty levels: the simplest problems used two numbers both divisible by 10 (e.g., 10 + 40), and the most difficult used two odd numbers that were not divisible by 10 and were greater than 19 (e.g., 29 + 47). Task difficulty was adaptive; during each session, the task began by presenting low-difficulty problems (e.g., 10 + 40) and became progressively more difficult with correct responses. If the first trial of a particular difficulty level was correctly answered, the next difficulty level would be presented. If a participant fell below 50% accuracy in a sequence of 3 or more trials, the difficulty level would automatically decrease. Each problem was presented for 1 s, and to increase time pressure the participant was provided with only a 3 second response window. In the event of a correct response, a 300 ms chime sound was played, and an error or non-response was followed by a 300 ms buzzer sound. Each successive trial was preceded by a 1 second inter-trial interval and central fixation cross. Mental arithmetic tasks have been shown to reliably induce acute stress responses as measured by self-report mood instruments, electrophysiology, and stress biomarkers such as salivary α-amylase (Jern, Pilhall, Jern, & Carlsson, 1991; Noto, Sato, Kudo, Kurata, & Hirota, 2005; Ring, Drayson, Walkey, Dale, & Carroll, 2002). A pilot study (n = 8) showed this particular task increased tension and anxiety subscores on the Profile of Mood States (POMS; Pollock, Cho, Reker, & Volavka, 1979).

4. Procedure

Participants visited the laboratory for a practice session and then six separate test sessions, each separated by at least two days. During the practice session, participants provided demographics, completed the individual differences measures and practiced the test day procedures, including completing the BMIS and practice trials of the arithmetic task.

Each test session took place in the morning following a 12-hour water-only fast (including no consumption of caffeine, herbal supplements, or over the counter medications), at a consistent time within participants and lasted approximately 2 h. Upon arrival for a test session, participants completed a baseline BMIS, and then were given the treatment capsule (containing either 200 mg L-theanine or placebo) along with a 12-ounce bottle of water. Thirty five minutes later (to allow for metabolism of L-theanine; Kimura et al., 2007; Rogers, et. al., 2008), they again completed the BMIS and then began the 15-minute breathing exercise (either focused, unfocused or worry). Following the breathing exercise, they completed the BMIS, performed the 20-minute arithmetic task, and then again completed the BMIS.

5. Results

5.1. Scoring & analysis

The MARS was scored by summing the math test anxiety items; the overall Cronbach's α in this sample was excellent (α = .92). The MAAS was scored by averaging responses for each of the 15 items; the overall Cronbach's α in this sample was good (α = .83). The FFMQ was scored by separately summing responses for each of the five factors, reverse-scoring when necessary. For the FFMQ, the five scale-specific Cronbach's α values ranged from acceptable to excellent (α = .73, .90, .87, .92, .83, respectively).

The OSPAN was scored by summing the number of words correctly recalled across trials; a recalled set of words was correct only if a participant recalled all words in the correct order. BMIS reliability indexed using Cronbach's α in this sample was overall good (α = .88).

For standardized achievement test scores, the majority of participants provided scores from the Scholastic Aptitude Test (SAT), though some from only the American College Testing (ACT) exam; in the latter case, ACT scores were converted to SAT scores using procedures established by the University of California (http://www.ucsd.edu/catalog/front/ACTtoSAT.html).

In the following sections, statistical results are accompanied by Cohen's *d* (t-tests) or eta-squared (η^2).

5.2. Math anxiety groups

Participants varied widely in math anxiety levels ($M = 45.3$, $SD = 12.7$; range of 15–67). A frequency histogram indicated a bimodal distribution of math anxiety scores, peaking in the 30–40 range (low) and 50–60 range (high). A median split at 46.5 produced two groups, one relatively low ($M = 34.6$, $SD = 7.5$) and one high in math anxiety ($M = 55.9$, $SD = 6.1$). Table 1 details the composition of these two groups, including comparative statistics.

Supporting Hypothesis #1, the high (versus low) math-anxious group showed lower math (but not verbal) subtest performance on standardized achievement tests. Supporting Hypothesis #2, the high (versus low) math-anxious group showed lower working memory capacity.

6. Focused breathing and L-theanine: effects on math anxiety

6.1. Mood (BMIS) results

Recall that BMIS ratings were sampled at four points within each of the six sessions: upon arrival to the session (Baseline), immediately following capsule consumption, immediately following the breathing exercise, and again immediately following the arithmetic test. For the BMIS, our scoring procedures followed Mayer and Gaschke (1988); we focused our analyses on two items that were highly relevant to our hypotheses: Nervous and Calm, and created a composite measure (Calm–Nervous) to index degree of calmness while accounting for rated nervousness. To standardize scores within an individual, we calculated a difference score that reflected each of these three Time points after subtracting Baseline ratings (see Table 2). An omnibus 3(Breathing: focused, unfocused, worry) × 2(L-theanine: 0 mg, 200 mg) × 2(Math Anxiety: low, high) × 3(Time: post-capsule, post-breathing, post-math task) mixed analysis of variance (ANOVA) demonstrated a main effect of Time, $F(2, 68) = 13.76$, $p < .01$, $\eta^2 = .03$.

The effect of Time was qualified by two interactions, one between Time and Math Anxiety, $F(2, 68) = 4.0$, $p < .05$, $\eta^2 = .01$, and the other between Time and Breathing, $F(4, 136) = 2.88$, $p < .05$, $\eta^2 = .01$. In examining the first interaction, the two math anxiety groups only showed a calmness difference at Post-Math, with the Low Math Anxiety group showing significantly higher calmness ratings relative to the High Math Anxiety group, $t(34) = 1.97$, $p < .05$, Cohen's $d = .65$ (all other t's < 1). In examining the second interaction, three simple effects ANOVAs showed no effect of Breathing at post-capsule, $F(2, 70) = .16$, $p > .05$, $\eta^2 < .01$. Following the 15-minute exercise, however, there was an effect of Breathing, $F(2, 70) = 3.96$, $p < .05$, $\eta^2 = .10$, with highest rated calmness in the Focused condition, followed by the Unfocused, and then the Worry condition (see Table 2), supporting Hypothesis #3. Finally, at post-math task, though the pattern was similar to at post-breathing, the effect of Breathing was mitigated, $F(2, 70) = .61$, $p > .05$, $\eta^2 < .01$. L-theanine supplementation also appeared to increase composite calmness, but this pattern only approached marginal significance, $F(1, 34) = 2.2$, $p = .14$, $\eta^2 = .01$.

6.2. Arithmetic task results: accuracy

Recall that there were five task difficulty levels; across the two Math Anxiety groups, there was no significant difference in the proportion of trails in each of the five difficulty groups ($M_{\text{level1, lowanx}} = .008$, $M_{\text{level1, highanx}} = .01$; $M_{\text{level2, lowanx}} = .025$, $M_{\text{level2, highanx}} = .031$; $M_{\text{level3, lowanx}} = .009$, $M_{\text{level3, highanx}} = .011$; $M_{\text{level4, lowanx}} = .007$, $M_{\text{level4, highanx}} = .009$; $M_{\text{level5, lowanx}} = .951$, $M_{\text{level5, highanx}} = .936$), as confirmed by no interaction ($p = .84$) or main effect of Math Anxiety ($p = .77$) in a 2(Math Anxiety: low, high) × 5(Difficulty Level: 1,2,3,4,5) ANOVA. When considering accuracy, however, at the lower difficulty levels (1–2) the two Math Anxiety groups showed similarly high accuracy ($M_{\text{level1, lowanx}} = .91$, $M_{\text{level1, highanx}} = .92$;

Table 2
Mean and standard deviation composite calmness difference scores (minus baseline) for the two math anxiety groups (low/high), three Breathing conditions, and three Time Samples.

Math group	Breathing	Post-capsule		Post-breathing		Post-math test	
		M	*SD*	*M*	*SD*	*M*	*SD*
Low math anxiety	Focused	0.04	0.71	0.50	0.84	0.17	0.64
	Unfocused	0.06	0.70	0.25	0.90	−0.08	1.10
	Worry	0.08	0.62	0.11	1.03	0.11	0.83
High math anxiety	Focused	0.00	0.34	0.63	0.87	0.17	0.64
	Unfocused	0.14	0.72	0.36	0.90	−0.22	1.25
	Worry	0.03	0.69	−0.11	0.66	−0.58	0.81

$M_{\text{level2, lowanx}} = .81$, $M_{\text{level2, highanx}} = .83$; all t's < 1). In each of the three higher difficulty levels (3–5), however, accuracy varied significantly as a function of Math Anxiety (all p's < .05). In these more demanding conditions, the high math-anxious group showed lower overall accuracy ($M = .61$, $SD = .22$) on the arithmetic task relative to the low math anxious group ($M = .75$, $SD = .19$), supporting Hypothesis #1.

An omnibus 3(Breathing: focused, unfocused, worry) × 2(L-theanine: 0 mg, 200 mg) × 2(Math Anxiety: low, high) mixed analysis of variance (ANOVA) on accuracy data from the three highest difficulty levels demonstrated main effects of Breathing, $F(2, 64) = 5.03$, $p < .01$, $\eta^2 = .04$ and Math Anxiety, $F(1, 32) = 6.92$, $p = .01$, $\eta^2 = .18$, qualified by an interaction between these two factors, $F(2, 64) = 3.22$, $p < .05$, $\eta^2 = .02$, as depicted in Fig. 1. All other p's > .27.

To further examine the interaction, we separately examined Breathing effects within the two Math Anxiety groups. In the Low Math Anxiety group, a repeated-measures ANOVA revealed no effect ($F < 1$). In the High Math Anxiety group, there was a main effect of Breathing, $F(2, 34) = 5.96$, $p < .01$, $\eta^2 = .26$. Follow-up paired t-tests within the High Math Anxiety group revealed significantly higher accuracy in the Focused versus Unfocused conditions, $t(17) = 2.36$, $p < .05$, Cohen's $d = .56$, and Focused versus Worry conditions, $t(17) = 3.22$, $p < .01$, Cohen's $d = .76$, providing strong support for Hypothesis #4.

6.3. Arithmetic task results: response time

Response times during the three more difficult trial types showed the high math-anxious group responding slower ($M = 2298.2$, $SD = 97.2$) relative to the low math anxious group ($M = 2136.5$, $SD = 243.6$) (this effect was not found in the lower difficulty levels; t's < 1), as confirmed by a main effect of Math Anxiety, $F(1, 32) = 8.87$, $p < .01$, $\eta^2 = .22$, in an omnibus 3(Breathing: focused, unfocused, worry) × 2(L-theanine: 0 mg, 200 mg) × 2(Math Anxiety: low, high) mixed analysis of variance (ANOVA; all other p's > .16).

7. Discussion

In this study we assessed the potential of several brief interventions that might prove valuable in helping students regulate negative emotions and free up the mental resources necessary for performance during high pressure tests. Complementing the general contention that those with test anxiety show global testing impairment such as on the SAT and ACT (Cassady & Johnson, 2002), we found relatively specific effects of math anxiety on math subsection standardized test scores. The same effect was not found for verbal (reading) subtest performance. Together with working memory capacity results, our data indicate that math-anxious individuals underperform their low-anxious peers on both real-world math tests (SAT/ACT) and a laboratory-based task demanding the flexible maintenance and manipulation of information in working memory.

We also tested some hypotheses derived from attentional control theory (Eysenck et al., 2007); namely that by reducing anxious worry immediately prior to an arithmetic task, we might reduce the mental burden that anxiety places on cognitive performance. In doing so, we would enhance the ability of the math anxious to perform arithmetic tasks under pressure. Our results support this hypothesis. When performing a laboratory arithmetic test designed to simulate a time-pressured testing situation, we found that participants with high math anxiety underperformed by approximately 14% relative to their low math anxiety peers. Of course, there is no reason to believe that the high-anxious group did not have the ability to solve these somewhat basic addition problems; indeed all participants showed SAT math subject test scores of at least 500 points. Performance differences were only observed when problems became more mentally demanding, such as requiring the carrying and more active monitoring and updating of sequences of operations. The most compelling result was found when math-anxious participants performed a focused breathing exercise immediately prior to the arithmetic test. After the exercise they showed a 9% boost in accuracy relative to the worry exercise (and a 6% boost relative to the unfocused breathing condition), allowing them to approach the performance levels of participants with low math anxiety. The focused breathing exercise was specifically designed to reduce feelings of anxiety and aid in the effortful control of attention, allowing participants to focus on something other than the negative emotional thoughts about the math test. Even with these advantages of focused breathing, we note that this particular exercise was not able to boost performance to the extent that the low and high math anxious individuals showed equivalent performance; indeed the high math anxious still underperformed their low anxious peers by approximately 8% following focused breathing. Longer-term mindfulness practices might prove effective in narrowing this gap, though this remains an empirical question.

7.1. Theoretical implications

Why might focused breathing be advantageous for math testing performance amongst the math-anxious? Humans have limited capacity

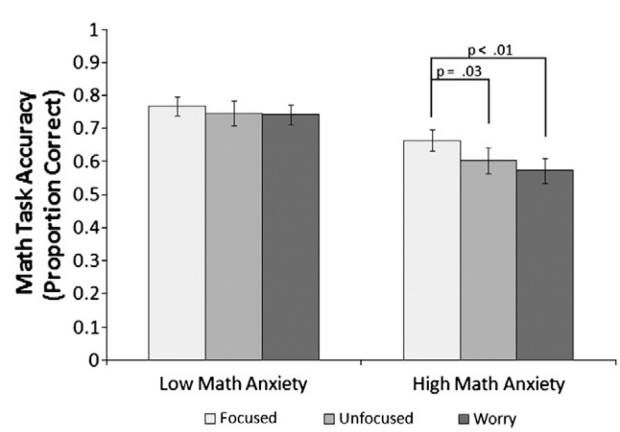

Fig. 1. Mean math task accuracy (proportion correct) and standard error, as a function of the three Breathing conditions: focused, unfocused, worry. Statistics derived from planned comparisons using paired t-tests.

for the processing and manipulation of information in working memory (cf., Miyake & Shah, 1999). Behavioral and cognitive neuroscience research suggests that actively regulating emotions recruits structural and functional brain mechanisms that are also responsible for actively controlling and deploying attentional resources (Ochsner & Gross, 2005). Brief focused breathing exercises improve the control of attention (Tang et al., 2007) and aid in regulating negative emotions during stressful situations (Arch & Craske, 2006). Individuals with high math anxiety are likely to devote considerable cognitive resources to regulating their feelings of worry, and processing constraints emerge during more demanding arithmetic operations (Beilock & Carr, 2005). A brief bout of focused breathing, however, was able to train the effective control of attention away from the distressing feelings and ultimately free up cognitive resources to focus attention on the mathematical operations. Our results support more recent theories positing important interactions between emotion and cognition; for instance, attentional control theory (Eysenck et al., 2007). Under this theory, anxious states consume mental resources that might otherwise be devoted to the effortful control of attention, particularly when participants engage in tasks that demand central executive involvement (such as difficult arithmetic operations; Hitch, 1978; Logie et al., 1994). Indeed attentional control theory has been a valuable framework for understanding how anxiety can produce poor test performance among children (Owens, Stevenson, Norgate, & Hadwin, 2008). Herein we find that similar relationships might prove at least partially responsible for test performance among college students.

In contrast to the effects found with the focused breathing exercise, L-theanine supplementation did not produce consistent effects on mood state or test performance. Though 200 mg of L-theanine did lead to some calming relative to placebo (in support of prior work; Kimura et al., 2007), we note that this effect did not reach marginal significance. In turn, L-theanine did not significantly affect math testing performance. We add to the mixed results calling into question the putative effects of L-theanine on human affect and cognitive performance. One possible explanation for differential effects is varied tea consumption rates across participant samples. In the present sample, the majority of participants (26/36) reported some level of tea consumption; it is possible that L-theanine's anxiogenic effects are diminished in individuals who commonly consume products containing L-theanine (Rogers et al., 2008). Though plausible, exploratory regressions using individual differences in tea consumption revealed no value in predicting affect or testing data. Further, it is difficult to compare our sample characteristics to the extant literature given that most studies finding L-theanine effects on affective state fail to report participant consumption rates (Haskell et al., 2008; Kimura et al., 2007).

7.2. Applied implications and limitations

Several studies have demonstrated that adopting long-term mindfulness-based interventions in classroom settings holds promise for increasing student engagement, positive affect, compliance, and test performance (for a review see; Burke, 2010). These programs, however, are often time intensive for both students and teachers (e.g., 2–14 weeks), costly, and show attrition (Laselle & Russell, 1993). We began this research by suggesting the potential for several short-term interventions to decrease negative emotions and enhance attentional control, with the goal of building a resource toolkit of short-term interventions which students and instructors alike can easily implement. As reviewed in the Introduction, math anxiety is a primary impediment to student success in both STEM coursework and careers. The present results suggest that a short bout of focused breathing exercise can boost performance of students with high math anxiety when they attempt a high pressure arithmetic task. Short-term focused breathing exercises may therefore present a practical and tractable solution for supporting test performance amongst the math anxious.

Though the present results show promise for enhancing test performance, it also carries limitations that should motivate further research. First, our participants were sampled from a highly selective private university with a potentially limited range of knowledge and ability. Though it is compelling that we found enhanced performance among the math anxious, more work is needed before understanding whether our results generalize to more varied student populations in terms of age (e.g., middle and high school), knowledge and ability. Second, our manipulations did not include a condition that promoted worry specifically about the upcoming test. We chose to include the unfocused condition to allow test-related thoughts to enter participants' minds; of course, we cannot guarantee that participants thought about the upcoming test in this condition. Future research might compare our unfocused condition to a condition that specifically encourages the type of rumination math anxious individuals might experience immediately prior to an exam. Third, people vary widely in their propensity towards and acceptance of mindfulness-based practices (Brown & Ryan, 2003). Though our sample tended to show moderate to high levels of trait mindfulness (as measured via the MAAS), sampling from more varied populations may demonstrate limited acceptance of a focused breathing exercise among both students and teachers. Finally, we note that the OSPAN working memory task uses simple arithmetic problems (e.g., $1 + 8 = 5$; True or False?) to induce interference during word memorization; it is possible that high math anxious individuals underperformed on the OSPAN simply due to anxiety regarding this particular OSPAN attribute. Though this is certainly possible (see Ashcraft & Kirk, 2001), we find this unlikely given no evidence of group differences in our timed arithmetic task at difficulty levels resembling the OSPAN arithmetic problems.

7.3. Conclusions

In the 2008 report issued by the United States National Mathematics Advisory Panel, the Panel recommended the “development of promising interventions for reducing” math anxiety (U.S. Department of Education, 2008). Recent work has begun identifying the utility of short-term interventions for effectively managing negative emotions and supporting students' experiences with formal mathematics tasks and assessments. Our research takes an important step towards this goal by validating a tractable real-world strategy for enhancing test performance amongst those with high math anxiety. A brief focused breathing exercise appears to help students regulate negative emotions and marshal the cognitive resources necessary to control anticipatory anxiety immediately prior to a math testing situation.

References

Alexander, L., & Cobb, R. (1987). Identification of the dimensions and predictors of math anxiety among college students. *Journal of Human Behavior and Learning*, *4*(1), 25–32.

Arch, J. J., & Craske, M. G. (2006). Mechanisms of mindfulness: Emotion regulation following a focused breathing induction. *Behaviour Research and Therapy*, *44*, 1849–1858. http://dx.doi.org/10.1016/j.brat.2005.12.007.

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

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology. General*, *130*, 224–237. http://dx.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*, 243–248. http://dx.doi.org/10.3758/BF03194059.

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

Brown, K. W., & Ryan, R. M. (2003). The benefits of being present: Mindfulness and its role in psychological well-being. *Journal of Personality and Social Psychology*, *84*, 822–848. http://dx.doi.org/10.1037/0022-3514.84.4.822.

Burke, C. A. (2010). Mindfulness-based approaches with children and adolescents: A preliminary review of current research in an emergent field. *Journal of Child and Family Studies*, *19*(2), 133–144.

Carlson, L. E., & Brown, K. W. (2005). Validation of the mindful attention awareness scale in a cancer population. *Journal of Psychosomatic Research*, *58*(1), 29. http://dx.doi.org/10.1016/j.jpsychores.2004.04.366.

Cassady, J. C., & Johnson, R. E. (2002). Cognitive test anxiety and academic performance. *Contemporary Educational Psychology*, *27*, 270–295. http://dx.doi.org/10.1006/ceps.2001.1094.

de Bruin, E. I., Topper, M., Muskens, J. G., Bögels, S. M., & Kamphuis, J. H. (2012). Psychometric properties of the Five Facets Mindfulness Questionnaire (FFMQ) in a meditating and a non-meditating sample. *Assessment*, *19*, 187–197. http://dx.doi.org/10.1177/1073191112446654.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science*, *11*, 19–23. http://dx.doi.org/10.1111/1467-8721.00160.

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

Faust, M. W., Ashcraft, M. H., & Fleck, D. E. (1996). Mathematics anxiety effects in simple and complex addition. *Mathematical Cognition*, *2*, 25–62. http://dx.doi.org/10.1080/135467996387534.

Geary, D. C., & Widaman, K. F. (1992). Numerical cognition: On the convergence of componential and psychometric models. *Intelligence*, *16*, 47–80. http://dx.doi.org/10.1016/0160-2896(92)90025-M.

Gomez-Ramirez, M., Higgins, B. A., Rycroft, J. A., Owen, G. N., Mahoney, J., Schpaner, M., et al. (2007). The deployment of intersensory selective attention: A high-density electrical mapping study of the effects of theanine. *Clinical Neuropharmacology*, *30*, 25–38. http://dx.doi.org/10.1097/01.WNF.0000240940.13876.17.

Haskell, C. F., Kennedy, D. O., Milne, A. L., Wesnes, K. A., & Scholey, A. B. (2008). The effects of L-Theanine, caffeine and their combination on cognition and mood. *Biological Psychology*, *77*, 113–122. http://dx.doi.org/10.1016/j.biopsycho.2007.09.008.

Hitch, G. J. (1978). The role of short-term working memory in mental arithmetic. *Cognitive Psychology*, *10*, 302–323. http://dx.doi.org/10.1016/0010-0285(78)90002-6.

Jern, S., Pilhall, M., Jern, C., & Carlsson, S. G. (1991). Short-term reproducibility of a mental arithmetic test. *Clinical Science*, *81*, 593–601.

Juneja, L. R., Chu, D. C., Okubo, T., Nagato, Y., & Yokogoshi, H. (1999). L-Theanine—A unique amino acid of green tea and its relaxation effect in humans. *Trends in Food Science & Technology*, *10*, 199–204. http://dx.doi.org/10.1016/S0924-2244(99)00044-8.

Kabat-Zinn, J. (2005). *Guided Mindfulness Meditation [CD]*. Louisville, CO: Sounds True.

Kimura, K., Ozeki, M., Juneja, L., & Ohira, H. (2007). L-Theanine reduces psychological and physiological stress responses. *Biological Psychology*, *74*, 39–45. http://dx.doi.org/10.1016/j.biopsycho.2006.06.006.

Kozhevnikov, M., Louchakova, O., Josipovic, Z., & Motes, M. A. (2009). The enhancement of visuospatial processing efficiency through Buddhist diety meditation. *Psychological Science*, *20*, 645–653. http://dx.doi.org/10.1111/j.1467-9280.2009.02345.x.

Laselle, K. M., & Russell, T. T. (1993). To what extent are school counselors using meditation and relaxation techniques? *School Counselor*, *40*(3), 178–183.

Logie, R. H., Gilhooly, K. J., & Wynn, V. (1994). Counting on working memory in arithmetic problem solving. *Memory & Cognition*, *22*, 395–410. http://dx.doi.org/10.3758/BF03200866.

Lu, K., Gray, M., Oliver, C., Liley, D., Harrison, B., Bartholomeusz, C., et al. (2004). The acute effects of L-Theanine in comparison with alprazolam on anticipatory anxiety in humans. *Human Psychopharmacology*, *19*, 457–465. http://dx.doi.org/10.1002/hup.611.

Lutz, A., Brefczynski-Lewis, J. A., Johnstone, T., & Davidson, R. J. (2008). Voluntary regulation of the neural circuitry of emotion by compassion meditation: Effects of expertise. *PLoS One*, *3*, 1897. http://dx.doi.org/10.1371/journal.pone.0001897.

Mayer, J. D., & Gaschke, Y. N. (1988). The experience and meta-experience of mood. *Journal of Personality and Social Psychology*, *55*, 102–111. http://dx.doi.org/10.1037//0022-3514.55.1.102.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 40–100. http://dx.doi.org/10.1006/cogp.1999.0734.

Miyake, A., & Shah, P. (Eds.). (1999). *Models of working memory: Mechanisms of active maintenance and executive control*. New York: Cambridge University Press. http://dx.doi.org/10.1017/CBO9781139174909.

Noto, Y., Sato, T., Kudo, M., Kurata, K., & Hirota, K. (2005). The relationship between salivary biomarkers and state-trait anxiety inventory score under mental arithmetic stress: A pilot study. *Anesthesia and Analgesia*, *101*, 1873–1876. http://dx.doi.org/10.1213/01.ANE.0000184196.60838.8D.

Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *Trends in Cognitive Sciences*, *9*, 242–249. http://dx.doi.org/10.1016/j.tics.2005.03.010.

Owens, M., Stevenson, J., Norgate, R., & Hadwin, J. A. (2008). Processing efficiency theory in children: working memory as a mediator between test anxiety and academic performance. *Anxiety, Stress and Coping*, *21*(4), 417–430. http://dx.doi.org/10.1080/10615800701847823.

Perry, A. B. (2004). Decreasing math anxiety in college students. *College Student Journal*, *38*, 321.

Pollock, V., Cho, D. W., Reker, D., & Volavka (1979). Profile of mood states: The factors and their physiological correlates. *The Journal of Nervous and Mental Disease*, *167*, 612–614. http://dx.doi.org/10.1097/00005053-197910000-00004.

Ramirez, G., & Beilock, S. L. (2011). Writing about testing worries boosts exam performance in the classroom. *Science*, *331*, 211–213. http://dx.doi.org/10.1126/science.1199427.

Ring, C., Drayson, M., Walkey, D. G., Dale, S., & Carroll, D. (2002). Secretory immunoglobulin A reactions to prolonged mental arithmetic stress: Inter-session and intra-session reliability. *Biological Psychology*, *59*, 1–13. http://dx.doi.org/10.1016/S0301-0511(01)00128-4.

Rogers, P. J., Smith, J. E., Heatherley, S. V., & Pleydell-Pearce, C. W. (2008). Time for tea: Mood, blood pressure and cognitive performance effects of caffeine and theanine administered alone and together. *Psychopharmacology*, *195*, 569–577. http://dx.doi.org/10.1007/s00213-007-0938-1.

Rounds, J., & Hendel, D. D. (1980). Measurement and dimensionality of mathematics anxiety. *Journal of Counseling Psychology*, *2*, 138–149. http://dx.doi.org/10.1037/0022-0167.27.2.138.

Suinn, R. M., & Winston, E. H. (2003). The Mathematics Anxiety Rating Scale, a brief version: Psychometric data. *Psychological Reports*, *92*, 167–173. http://dx.doi.org/10.2466/PR0.92.1.167-173.

Tang, Y. -Y., Ma, Y., Wang, J., Fan, Y., Feng, S., Lu, Q., et al. (2007). Short-term meditation training improves attention and self-regulation. *Proceedings of the National Academy of Sciences*, *104*, 17152–17156. http://dx.doi.org/10.1073/pnas.0707678104.

U.S. Department of Education (2008). *Foundations for success: The final report of the National Mathematics Advisory Panel*. Washington, D.C.: U.S. Department of Education.

Wenk-Sormaz, H. (2005). Meditation can reduce habitual responding. *Alternative Therapies in Health and Medicine*, *11*, 32–58.