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## **The Impact of Mathematics Anxiety on Stress Appraisals, Neuroendocrine Responses, and Academic Performance in a Community College Sample**

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# The Impact of Mathematics Anxiety on Stress Appraisals, Neuroendocrine Responses, and Academic Performance in a Community College Sample

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Mathematics anxiety is a major impediment to achievement in mathematics and science academic domains. Although important steps have been made in understanding the psychological processes of mathematics anxiety, as well as developing promising interventions, less is known about the relationship among mathematics anxiety, affective and biological responses, and achievement in stressful performance contexts. Toward this end, the research presented here recruited community college students ( $N = 478$ ) from 30 mathematics classrooms, and examined associations among mathematics anxiety, stress appraisals, neuroendocrine reactivity (cortisol and testosterone), and exam scores. Higher levels of mathematics anxiety associated with students perceiving more demand and fewer coping resources in exam settings, lower levels of testosterone on exam days relative to baseline, and worse exam performance. Moreover, associations among mathematics anxiety, and neuroendocrine reactivity and performance were partially mediated by stress appraisals. Implications for student achievement, wellbeing, and intervention development are discussed.

### *Educational Impact and Implications Statement*

This research examined associations among mathematics anxiety, stress processes, and classroom performance in community college students. Higher levels of mathematics anxiety predicted more negative stress responses and lower exam scores. This research highlights how psychological factors associate with biological functioning and objective academic outcomes in an understudied population.





*Keywords:* mathematics anxiety, stress, psychophysiology, community college

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Proficiency in science, technology, engineering, and mathematics (STEM) is imperative for flexibly addressing 21st century challenges. Because of the importance of STEM training at the

societal and individual levels, the educational system of the United States has emphasized STEM learning goals and sought to improve STEM education for decades (Bybee, 2010). Not only are STEM-oriented technical skills and training important, but psychological factors surrounding STEM topics are highly relevant for thriving in a rapidly advancing technological world. These psychological factors include mindsets, goals, and learning strategies, to name a few, and they play important roles in facilitating or hindering academic achievement (e.g., Elliot & Hulleman, 2017; Hangen, Elliot, & Jamieson, 2019; Honicke & Broadbent, 2016; Rattan, Savani, Chugh, & Dweck, 2015).

In STEM domains in particular, mathematics anxiety is negatively linked to achievement, and alleviating the effects of mathematics anxiety can go a long way toward promoting positive outcomes (for a review see Ramirez, Shaw, & Maloney, 2018). Although promising steps have been made toward developing interventions to attenuate mathematics anxiety (e.g., Jamieson, Peters, Greenwood, & Altose, 2016; Park, Ramirez, & Beilock, 2014; Rozek, Ramirez, Fine, & Beilock, 2019) and toward better understanding moderating factors (Maloney, Ramirez, Gunderson,

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Levine, & Beilock, 2015; Ramirez, Gunderson, Levine, & Beilock, 2013), less is known about how mathematics anxiety relates to stress processes, neuroendocrine responses, and achievement. Toward this end, the research presented here recruited community college students and examined relationships among mathematics anxiety, stress appraisals, cortisol and testosterone responses, and exams scores in classroom settings. First, we review theory on mathematics anxiety, followed by coverage of stress models with an emphasis on anxiety processes. Finally, we highlight the particular importance of studying mathematics anxiety processes in community college samples.

### Mathematics Anxiety

Mathematics anxiety is operationalized as avoidance oriented negative affect—feelings of fear, tension, and apprehension in particular—that manifests when engaging with mathematics (Ashcraft, 2002). Research suggests that, similar to other persistent mental health problems rooted in anxiety processes, the experience of mathematics anxiety may be a stable and trait-like factor that is independent of broad test anxiety (Kazelskis et al., 2000) and state anxiety (Hembree, 1990). In fact, individuals experiencing high levels of mathematics anxiety not only exhibit a dislike of mathematics and avoidance of mathematics courses, but in mathematics settings they can also experience neural responses akin to pain (Lyons & Beilock, 2012).

Not surprisingly, meta-analytic data indicates that higher mathematics anxiety levels predict worse mathematics achievement across multiple samples of students ( $r = -.27$ , Ma, 1999), and more globally, worse educational outcomes in an array of STEM domains (Foley et al., 2017). Multiple theoretical models have been proposed to account for associations between mathematics anxiety and achievement. Notably, competency and disruption accounts have received much support in the literature (for a review see Ramirez et al., 2018). The competency model posits that mathematics anxiety is a proxy for poor mathematics ability. Thus, anxiety can be an *outcome* of low competency (Maloney, 2016), but also lead to subsequent negative outcomes via avoidance processes (Ashcraft & Kirk, 2001). The disruption account (e.g., Ramirez et al., 2018) theorizes that mathematics anxiety leads to poor outcomes via transient cognitive processes. In this model mathematics anxiety is not an outcome of poor performance, but rather a cause of performance decrements. Taken together, these models can synergistically describe how mathematics anxiety can have recursive effects. For instance, disruption processes can lead to negative performance on a mathematics exam, then competency models suggest the negative performance can become internalized as students perceive they lack ability in mathematics. Downstream, this perceived lack of ability can open the door for additional disruption processes, and so on.

The experience of mathematics anxiety, however, is not a unitary construct. Rather, anxiety surrounding mathematics taps into negative affect in at least two ways: engaging with mathematics and/or being evaluated in mathematics (e.g., Hopko, Mahadevan, Bare, & Hunt, 2003). *Mathematics learning anxiety* refers to the experience of anxiety tied to learning situations, such as listening to a lecture or reading a textbook. *Mathematics evaluation anxiety* refers to anxiety stemming from the potential for evaluation, such as taking an exam or answering a question in class. This distinction

can be important when seeking to understand how mathematics anxiety is experienced across different educational contexts. For instance, in research examining standardized testing performance, evaluation anxiety is a more central process than learning anxiety. Alternatively, consider a highly mathematics-anxious college student selecting courses. Both learning anxiety and evaluation anxiety can play a role in decisions to avoid taking mathematics courses—learning anxiety processes activate in anticipation of instruction and studying, whereas evaluation anxiety processes activate as the student considers future exams and assessments.

The experience of mathematics anxiety can be stressful (Faust, 1992), and higher levels are associated with maladaptive stress responses and poor performance ( $\beta = -.26$ , Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011). In stressful situations students or learners must marshal resources to address acute demands of learning mathematics or performing a mathematics assessment. Understanding associations between mathematics anxiety and stress responses is important because of the substantial role of stress and stress coping in determining downstream health outcomes. Those high in mathematics anxiety are likely to perceive they do not possess the necessary resources to meet the demands of mathematics situations and experience avoidance-oriented stress responses (Jamieson et al., 2016). Similar to how stress processes explain negative associations among evaluation anxiety and physiological and performance outcomes (Jamieson, Koslov, Nock, & Mendes, 2013), we posit that experiences of mathematics anxiety may also lead to negative outcomes via stress processes. In the stress literature, appraisal processes guide stress responses (Jamieson, 2017), but stress appraisals have not been examined in conjunction with mathematics anxiety, neuroendocrine functioning, and classroom performance.

### Stress Appraisals and Anxiety

Experiences of anxiety are characterized by high levels of sympathetic arousal (Jamieson, Nock, & Mendes, 2013), poor cognitive functioning/performance (Shields, Moons, Tewell, & Yonelinas, 2016), and avoidance motivation (Elliot & McGregor, 1999). This pattern maps well onto the conceptualization of “threat” in the stress literature. More specifically, the biopsychosocial (BPS) model of challenge and threat theorizes that appraisals of demands (e.g., perceptions of uncertainty, danger, and required effort) and resources (e.g., perceptions of familiarity, knowledge, skills/ability, and social support) operate in concert to elicit challenge- and threat-type stress responses (for a review see Jamieson, Crum, Goyer, Marotta, & Akinola, 2018). Challenge is experienced when resources are appraised as exceeding demands. Alternatively, threat manifests when demands are appraised as exceeding resources, and commonly observed when individuals experience anxiety (Jamieson, Nock, et al., 2013).

Importantly, stress appraisals are multidimensional and multifaceted (for a review see Blascovich, 2008). Consider a student preparing for an exam. Studying and learning the material can impact both resource and demand appraisals. For instance, mastering new material is associated with higher perceptions of knowledge and ability (resources) or decreased perceptions of uncertainty and effort (demands) in exam domains. The content of stress appraisals can also vary across time, situations, and people, and are considered context specific. For example, although the student

above might appraise more resources as a function of studying, preparing for an exam in one course would not be expected to increase resource appraisals when taking an exam in another course.

Stress appraisals then impact biological responses (Mendes & Park, 2014). Whereas challenge is associated with approach-oriented responses, such as higher levels of anabolic hormones (e.g., DHEA and testosterone) and lower levels of catabolic hormones (e.g., cortisol), the experience of threat—and anxiety—leads to avoidance-oriented responses, indicated by lower anabolic hormones and elevated catabolic hormones (e.g., Akinola & Mendes, 2014; Jamieson, Koslov, et al., 2013; Schultheiss & Rohde, 2002). Notably, the differential motivational orientations that accompany challenge and threat responses—approach and avoidance, respectively—are important for learning outcomes and student achievement (Linnenbrink, 2005). Challenge and threat responses also have effects on decision-making (Kassam, Koslov, & Mendes, 2009) and health (Jefferson et al., 2010; Steptoe & Kivimäki, 2012).

In addition to BPS models, other theories highlight how anxiety and social submission influence neuroendocrine responses (e.g., Mazur & Booth, 1998; Mehta, Jones, & Josephs, 2008). For instance, dual hormone hypotheses (Mehta & Josephs, 2010) suggest anxiety or threat attenuates high status dominance-oriented responses, such as approach behaviors and increases in testosterone. Along these lines, research demonstrates that indicators of lower social status or anticipating social defeat suppress testosterone levels (e.g., Akinola & Mendes, 2008; Kraus & Mendes, 2014; Mazur, Booth, & Dabbs, 1992). More pertinent to the research questions posed here, highly socially anxious individuals exhibit decreased testosterone in stressful settings (Maner, Miller, Schmidt, & Eckel, 2008), which functions to limit approach-oriented behaviors in settings accompanied by low efficacy beliefs.

### Community College Students and Mathematics Anxiety

Community college students make up a large proportion (42%) of postsecondary students in the U.S. and almost half (47%) of all students who go on to earn degrees at 4-year colleges (Ma & Baum, 2016). Research by the Community College Research Center indicates 5.8 million students were enrolled in public, 2-year colleges in 2017. Moreover, community college students are disproportionately comprised of individuals from underrepresented minority groups (Carnevale, Van Der Werf, Quinn, Strohl, & Repnikov, 2018). Thus, community colleges provide an important avenue for reducing racial gaps in education and income in America.

Although there is a dearth of comprehensive empirical examinations of mathematics anxiety and achievement in community college students, preliminary findings suggest this group, and developmental students in particular, may experience particularly high levels of mathematics anxiety (Woodard, 2004). Consistent with this idea, research on adult learners—who comprise a large percentage of community college students—indicates these students experience more mathematics anxiety than “traditional” aged (i.e., 18–25) college students (Jameson & Fusco, 2014). Thus, studying how mathematics anxiety relates to stress processes and academic achievement in a large, diverse sample of commu-

nity college students can fill an important gap in the educational literature. Moreover, understanding psychological factors that can limit community college students’ achievement would allow researchers and educators to better tailor interventions and teaching methods for this large, but understudied, population of students.

### The Current Research

This research sought to contribute to the literature on mathematics anxiety by elucidating associations among mathematics anxiety, stress appraisals, neuroendocrine responses, and academic performance. Specifically, we posited that stress appraisals play a proximal role in explaining the link between mathematics anxiety, worse biological functioning, and lower academic achievement. To date, we are aware of no research examining relationships among these processes.

To answer our research questions, students from a large, urban community college system were recruited from 30 mathematics classrooms across 10 semesters and two campuses (Campus 1:  $n = 18$  classes; Campus 2:  $n = 12$  classes). Courses included diverse topics, including prealgebra, algebra, prestatistics, probability and statistics, trigonometry, and precalculus. Students first completed demographic questions and provided saliva samples on a nontesting class day (baseline). They then completed questionnaires—which included mathematics anxiety and stress appraisal measures—and provided another saliva sample immediately before beginning an in-class exam (reactivity). Then, students’ performance on the exams was measured.

Central hypotheses focused on *processes* underlying mathematics anxiety’s relationship with outcomes. First, increases in mathematics anxiety were expected to predict worse stress appraisals (high demands, lower resources), worse neuroendocrine functioning (lower testosterone levels and elevated cortisol), and poorer academic performance (lower exam scores). Second, stress appraisals were hypothesized to mediate associations between mathematics anxiety, and neuroendocrine and academic performance outcomes. Finally, an exploratory model tested the path from mathematics anxiety to stress appraisals to neuroendocrine responses to academic outcomes. That is, we were interested in the predictive utility of biological responses resulting from stress appraisals to inform academic outcomes.

Data are freely available at: [<https://socialstresslab.wixsite.com/urochester>]. We confirm that all measures collected and analyzed for this study are reported.

### Method

#### Targeted Sample Size

Data for this research were collected as part of a larger project funded by the U.S. Department of Education (R305A150036). To maximize statistical power, data were collected from 30 classes throughout the duration of the funded project. We confirm that no analyses were conducted for the current research until the termination of data collection at the end of the project.

To ensure that our sample size was sufficiently powered, we used the Optimal Design software package, developed by Raudenbush and colleagues to estimate power and/or determine sample sizes in multilevel designs (Spybrook et al., 2013). Our research

design corresponds to a two-level multisite trial with students nested within classrooms (henceforth referred to as cohorts). We estimated the following parameters: medium effect size of .3, effect size variance of .01, alpha level of .05, and 10% of variance accounted for by cohort (a conservative estimate given the study context). This analysis indicated that we needed an average of 12.21 students for each of the 30 cohorts, or a total  $N = 367$ , to achieve the traditional .80 level of statistical power. Thus, the final sample size for core mathematics anxiety analyses (after data exclusions) of  $N = 441$  was sufficiently powered.

## Participants

Students ( $N = 478$ ) were recruited from mathematics courses at an urban Midwestern community college system ( $M_{\text{age}} = 24.16$ ,  $\text{range} = 14\text{--}60$ ; 288 female, 190 male; 220 Black/African American, 193 White/Caucasian, 33 Latinx, 26 Asian, six Mixed/Other). Participants were prescreened and excluded for physician-diagnosed conditions that impact endocrine functioning, current medications with endocrine effects, and  $\text{BMI} > 30$ .

Two research assistants collected data from each of the college's two campuses. No monetary compensation was provided, as study materials were integrated with curriculum materials. Parental consent was obtained for three participants under 18 years of age.

## Procedure

Research staff recruited instructors to involve classrooms in the study via direct e-mails, flyers, and referrals. All participating instructors were provided a \$500 honorarium to help offset demands of study procedures on the design of their courses. All research activities herein were approved by the Institutional Review Board (IRB) at the corresponding author's home university as well as the IRB at the data collection site.

Once instructors provided access, research staff visited each classroom during the first week of the semesters to explain the study. During this visit students provided consent and completed demographic measures in class using paper-and-pencil questionnaires, then baseline saliva samples were collected (to be assayed for hormones). Note that paper-and-pencil methods were chosen for the in-class self-reports because of uncertainties about students' Internet access and the number of students per classroom (the research team had access to a finite number of tablet computers). All materials were delivered in a group setting—students completed materials at their desks/workspaces in class, but were given the option of providing saliva samples in a private area if they were uncomfortable expectorating saliva into the tube in the presence of peers.

After the baseline sessions, target measures were collected on the day of students' first exam. Prior to beginning exams, students completed assessments of mathematics anxiety and stress appraisals (pretested to take  $< 5$  min to complete). After students handed in questionnaires, they were given test tubes to collect saliva samples. Once students completed saliva samples, they were given their exams. Thus, students received their exams *after* completing all study materials to allow for psychological and neuroendocrine measures to serve as predictors.

Exams were designed to allow students sufficient time to complete study materials. If needed, students were given extra time

corresponding to time spent on study materials beyond the expected duration.

## Measures

**Mathematics anxiety.** Mathematics anxiety was assessed using the Abbreviated Mathematics Anxiety Scale (AMAS), which was constructed, validated, and replicated with a large student sample (Hopko et al., 2003). Consistent with previous research using the AMAS, a factor analysis conducted on the nine-item scale on our dataset yielded a two-factor solution, accounting for 68% of the variance determined using Cattell's "scree" test and eigenvalues. The two factors were best interpreted using the subscale designations of learning anxiety (in this sample, Cronbach's  $\alpha = .77$ ) and evaluation anxiety (Cronbach's  $\alpha = .80$ ) identified in previous research (Hopko et al., 2003). Composites were constructed for each subscale and analyzed separately (for a similar approach see Jamieson et al., 2016).

**Stress appraisals.** A measure from the social stress literature was adapted to index stress appraisals (Beltzer, Nock, Peters, & Jamieson, 2014; Jamieson et al., 2016; Mendes, Gray, Mendoza-Denton, Major, & Epel, 2007; Yeager, Lee, & Jamieson, 2016). This short-form four-item appraisal measure included two demand appraisal and two resource appraisal items. An exploratory factor analysis identified a two-factor solution that accounted for 75% of the variance using Cattell's "scree" test and eigenvalues. The two factors were best interpreted using the subscale designations of resource (Cronbach's  $\alpha = .74$ ) and demand appraisals (Cronbach's  $\alpha = .66$ ), which were then averaged into composites and analyzed separately (for a similar approach, see Yeager et al., 2016).

**Neuroendocrine responses.** Neuroendocrine functioning was measured by assessing cortisol and testosterone reactivity. Two 1-ml saliva samples were collected using passive drool procedures, in which participants expectorated saliva through a small straw into an IBL SaliCap collection device (Hamburg, Germany; test tubes were marked with a line indicating 1 ml). Participants were allowed up to 7 min to provide samples (for similar procedures, see Beltzer et al., 2014; Lee, Jamieson, Miu, Josephs, & Yeager, 2019; Peters, Hammond, Reis, & Jamieson, 2016; Yeager et al., 2016).

After collection, research staff transferred samples to a  $-30^\circ\text{C}$  biomedical freezer where they were stored until shipment for assay. At the completion of the study, samples were packed on dry ice and shipped to Brandeis University where they were analyzed for salivary free testosterone (Testosterone Saliva ELISA, Tecan). Samples were assayed in duplicate and outliers checked by re-assay. Inter- and intra-assay coefficients of variance were  $< 9\%$ . Due to an insufficient sample at either baseline or exam, neuroendocrine reactivity for 12 participants could not be analyzed.

As mentioned above, baseline samples were collected in class on a day without an evaluative assessment, whereas reactivity samples were collected immediately before students' first exam. It was important that baseline samples were collected in class on a day without an assessment to control for time of day (i.e., baseline and reactivity samples were collected at the same time of day) and classroom environment—that is, we were interested in students' neuroendocrine responses to stressful evaluative situations above and beyond typical functioning in a classroom environment. Because cortisol was a focal assessment, early morning classes were excluded (before 9:00 a.m.) to avoid peaks at waking.

To measure reactivity—or changes from baseline—we first standardized cortisol and testosterone levels at each timepoint (baseline and reactivity) *within* gender. That is, because of pronounced sex differences in testosterone reactivity and gender differences in associations between testosterone and cortisol (e.g., Juster et al., 2016), hormone levels (cortisol and testosterone) were standardized separately for males and females (see the online supplemental materials for raw means and standard deviations for men and women). Then, we subtracted standardized cortisol and testosterone levels collected on exam days from those collected at baseline. Note that cortisol and testosterone levels reflect circulating levels ~15–20 min prior to collection (e.g., Dabbs, 1993). Thus, we were interested in assessing neuroendocrine functioning *going into* exam situations, not *after* completing exams.

**Academic performance.** To examine classroom performance, we analyzed students' scores on their first in-class exam. Given that data were collected from 30 unique classrooms, students completed exams at different schedules (e.g., some classes held the first exam a week into the semester, while others held the first exam a full month into the semester) and different exams were used (e.g., an algebra course would necessarily include different questions than a statistics course). The common thread across all classrooms was that students were only recruited from mathematics courses.

A Levene's test indicated that there was nonsignificant heterogeneity in exam performance across the 30 classes,  $F(29, 309) = 1.06, p = .384$ . A one-way ANOVA examining the effect of class cohort on exam performance was, indeed, significant,  $F(29, 411) = 2.41, p < .001, \eta^2 = 0.146$  (grand  $M = 75.47\%$ ,  $SD = 14.91\%$ ). Thus, we sought to assess performance by examining students' standardized exam scores. To do so, exam scores were standardized *within* class and z-scores analyzed to index performance relative to class averages and account for differences in raw scores in scores across classrooms. Furthermore, the significant effect of class cohort on exam scores necessitated the use of multilevel analyses to control for within-cohort dependencies.

## Results

### Data Exclusions

Thirty-seven participants dropped the course after baseline measures were collected and were excluded from analyses. Thus, analyses of psychological variables and exam performance included a final sample of  $N = 441$ .

Of the remaining 441 participants, not all students provided saliva samples at baseline and on exam days. First, 81 participants (33 males, 48 females) opted out at baseline due to time constraints (i.e., insufficient classroom time allotted and/or needing more than 7 min to provide a viable sample) and concerns that genetic material would be extracted—even though research staff explicitly indicated that no genetic material would be analyzed. An additional five participants did not provide a sufficiently large sample at baseline for testosterone assays (cortisol immunoassays were performed first). Then, at the exam, neither cortisol nor testosterone could be assayed from eight participants who provided insufficient samples, and testosterone could not be assayed for an additional four participants due to insufficient samples.<sup>1</sup> In total, final analyses of neuroendocrine reactivity—which required that partic-

ipants provided samples at both time points (baseline and exam)—were:  $N = 352$  for cortisol, and  $N = 346$  for testosterone.

### Data Analysis Plan

Demographic information, basic correlations, descriptive statistics for the hormone variables by gender, and descriptive statistics for other predictors and outcomes, are reported in Tables 1, 2, and 3, and 4, respectively. Mathematics evaluation anxiety and learning anxiety were correlated,  $r = .53, p < .001$ , and thus each served as a control for the other in analyses. Demand and resource appraisals were negatively and moderately correlated,  $r = -.38, p < .001$ , and were kept separate instead of being combined in a composite. Predictor variables were grand-mean centered in multilevel analyses.

**Checking for outliers.** We first explored possible univariate and multivariate outliers. It was decided a priori that leverage and Cook's D would be used to identify outliers, and if any were identified, to winsorize those to values corresponding to 3  $SDs$  from the mean. First, we examined boxplots to establish univariate outliers, followed by computing leverage and Cook's D to identify multivariate outliers. Only hormone variables (testosterone and cortisol) exhibited outliers using a leverage cutoff criteria of .0628 and Cook's D  $> 1$ . In total 23 cases were winsorized.<sup>2</sup> Results for the hormone variables are based on the winsorized versions of these variables. Note, that results are essentially the same if raw scores were used in all analyses.

**Multilevel analyses.** Because students were nested within classrooms, a two-level hierarchical linear model was used to test hypotheses (Raudenbush & Bryk, 2002). Predictors were measured at the student level (Level 1), which were nested within cohorts (classrooms) at Level 2. Each predictor was included as a fixed effect, with random intercepts for each model.

We first tested for cohort effects (Level 2) to determine if variables differed across cohorts. Indeed, a one-way ANOVA examining the effect of cohort on exam scores was significant,  $F(29, 411) = 2.41, p < .001, \eta^2 = 0.146$ , justifying the necessity of using multilevel analyses to control for within-cohort dependencies.

### Effects of Mathematics Anxiety, Stress Appraisals, and Neuroendocrine Reactivity

**Mathematics anxiety.** We first tested if mathematics anxiety predicted stress appraisals. Mathematics learning anxiety negatively predicted resource appraisals,  $\beta = -0.30, t(427.61) = -3.08, p = .002$ , as did mathematics evaluation anxiety,  $\beta = -0.53, t(404.02) = -6.98, p < .001$  (see Table 5). Similarly, mathematics learning anxiety,  $\beta = 0.24, t(418.21) = 2.55, p = .011$ , and evaluation anxiety,  $\beta = 0.61, t(429.84) = 8.13, p < .001$ , also positively predicted demand appraisals. Taken together, higher mathematics learning *and* evaluation anxieties were linked to lower perceptions of coping resources and greater perceptions of demands in the exam context.

<sup>1</sup> There was not a significant difference in exam performance for participants excluded for not providing testosterone samples,  $t(439) = 0.87, p = .384$ , or for not providing cortisol samples,  $t(439) = 0.97, p = .335$ .

<sup>2</sup> The number of cases winsorized was eight for baseline cortisol, five for exam cortisol, six for baseline testosterone, and four for exam testosterone.

Table 1  
*Demographic Information*

Demographic variable	Frequency (percentage)
Biological sex	
Female	288 (60.3)
Male	190 (39.7)
Race/ethnicity	
White	193 (40.5)
Black	220 (46.2)
Latino(a)	33 (6.9)
Asian	26 (5.5)
Mixed/other	4 (0.8)
Age	
14–19	175 (38.5)
20–29	200 (44.1)
30–39	47 (10.4)
40–49	19 (4.1)
50–60	13 (2.9)

Next, we evaluated how mathematics anxieties predicted changes in cortisol and testosterone from baseline to the exam day. Reactivity scores were created by subtracting baseline hormone levels from the hormone level at the exam. Neither mathematics learning anxiety nor evaluation anxiety predicted cortisol reactivity,  $\beta = 0.05$ ,  $t(343.88) = 0.92$ ,  $p = .361$ ;  $\beta = -0.04$ ,  $t(317.61) = -0.92$ ,  $p = .361$ , respectively. Also, neither of the mathematics anxiety variables predicted testosterone reactivity,  $\beta_{learning} = -0.06$ ,  $t(341.27) = -1.30$ ,  $p = .195$ ;  $\beta_{evaluation} = -.04$ ,  $t(247.57) = -1.23$ ,  $p = .220$  (see Table 5).

Despite null neuroendocrine findings, we observed significant associations between the mathematics anxiety variables and exam performance. Mathematics learning anxiety negatively predicted performance,  $\beta = -3.90$ ,  $t(413.70) = -3.79$ ,  $p < .001$ , with higher levels of learning anxiety leading to lower scores on the exam. A similar pattern emerged with mathematics evaluation anxiety,  $\beta = -2.74$ ,  $t(418.22) = -3.37$ ,  $p = .001$ . Higher levels of evaluation anxiety predicted worse exam performance (see Table 5).

Taken together, these results suggest that experiencing higher levels of either mathematics learning or evaluation anxiety leads to

Table 2  
*Basic Correlations Among Variables*

Variable	MLeAnx	MEvAnx	Resource	Demand	T_Base	Cort_Base	T_Rx	Cort_Rx	Sex	Age	Exam
MLeAnx	1.00	.53**	-.34**	.33**	-.04	.03	.06	.07	.01	-.05	-.29**
MEvAnx	.53**	1.00	-.45**	.56**	-.02	-.02	.10*	.10*	-.09	-.08	-.28**
Resource	-.32**	-.39**	1.00	-.38**	-.03	.06	-.05	-.04	.16**	.09	.35**
Demand	.35**	.42**	-.36**	1.00	.04	-.14**	.09	.06	.01	-.08	-.28**
T_Base	-.04	-.03	-.01	-.00	1.00	.06	-.02	-.03	.02	-.12*	-.03
Cort_Base	.00	.03	.14**	-.08	.08	1.00	-.06	.01	.09	-.14*	.08
T_Rx	.10	.11	-.12**	.08	-.01	.04	1.00	.97**	-.05	.07	.04
Cort_Rx	.05	.09	-.08	.06	-.01	.07	.86**	1.00	-.05	.08	.05
Sex	.01	-.10	.18**	-.03	.01	.10	-.10	-.06	1.00	-.05	-.04
Age	-.04	.01	-.01	.07	-.11*	-.14**	.09	.05	-.04	1.00	-.05
Exam	-.31**	-.28**	.40**	-.28**	-.06	.07	-.03	-.02	-.00	-.01	1.00

Note. Values above the diagonal are the zero-order correlations and values below the diagonal are correlations controlling for class cohort. MLeAnx = mathematics learning anxiety; MEvAnx = mathematics evaluation anxiety; T\_Base = baseline testosterone levels; Cort\_Base = baseline cortisol levels; T\_Rx = testosterone reactivity (i.e. change from baseline to exam); Cort\_Rx = cortisol reactivity.

\*  $p < .05$ . \*\*  $p < .01$ .

Table 3  
*Means and Standard Deviations of Cortisol and Testosterone Levels by Gender*

Variable	$M_{female}$	$SD_{female}$	$M_{male}$	$SD_{male}$
Baseline cortisol	8.39	5.93	9.42	6.77
Cortisol at exam	10.37	7.78	11.87	7.93
Baseline testosterone	46.79	37.98	158.95	94.48
Testosterone at exam	48.16	40.61	152.07	102.44

lower resource appraisals, higher demand appraisals, and worse exam performance.

**Stress appraisals.** We then examined resource and demand appraisals as predictors in determining neuroendocrine responses and exam performance.

First, neither resource,  $\beta = -0.02$ ,  $t(342.90) = -0.87$ ,  $p = .387$ , nor demand,  $\beta = 0.01$ ,  $t(273.62) = .38$ ,  $p = .704$ , appraisals predicted cortisol reactivity (see Table 6). Demand appraisals also did not associate with testosterone reactivity,  $\beta = 0.01$ ,  $t(181.19) = 0.52$ ,  $p = .604$ . However, higher resource appraisals predicted testosterone reactivity,  $\beta = 0.08$ ,  $t(337.84) = 3.69$ ,  $p < .001$ . As high testosterone levels are associated with more positive and approach-oriented outcomes, this finding is consistent with the hypothesis that perceiving greater coping resources in an acutely stressful exam setting could lead to increases in testosterone.

Higher resource appraisals were also related to better exam performance,  $\beta = 3.19$ ,  $t(421.09) = 6.85$ ,  $p < .001$ . Consistent with this result, higher demand appraisals predicted worse exam performance,  $\beta = -1.84$ ,  $t(422.72) = -3.94$ ,  $p < .001$  (see Table 6). Appraising the demands of the course as more daunting negatively predicted performance on the exam.

**Neuroendocrine reactivity.** The final set of multilevel analyses focused on neuroendocrine responses as predictors of exam performance. Supporting the hypotheses, reactivity in both cortisol and testosterone were associated with exam scores. Cortisol reactivity predicted lower exam scores,  $\beta = -3.39$ ,  $t(342.77) = -3.12$ ,  $p = .002$ , whereas increases in testosterone predicted higher exam scores,  $\beta = 8.46$ ,  $t(337.43) = 6.26$ ,  $p < .001$  (see Table 7).

Table 4  
Means and Standard Deviations of the Predictor and Outcome Variables

Variable	Mean	Standard deviation
Mathematics learning anxiety	1.79	0.76
Mathematics evaluation anxiety	3.26	1.02
Resource appraisals	4.17	1.49
Demand appraisals	4.07	1.61
Exam performance	75.47	14.91

**Multilevel Mediation**

We conducted two sets of multilevel mediation analyses. The first included mathematics anxiety variables as predictors, stress appraisals as mediators, and testosterone reactivity as the outcome (cortisol was not included because of basic null effects). The second set included exam performance as the outcome. We used multilevel mediation to conduct analyses, so that the nested structure would continue to be controlled. In both sets of analyses, each mathematics anxiety variable was selected as the main initial predictor, with the other mathematics anxiety variable was included as a covariate for control purposes.<sup>3</sup>

**Testosterone reactivity.** With mathematics learning anxiety as the predictor, there was a significant indirect effect through resource appraisals on testosterone reactivity,  $\beta = -0.02$ ,  $SE = 0.01$ ,  $p = .033$ , 95% CI [-0.04, -0.01]. However, the indirect effect of mathematics learning anxiety through demand appraisals

Table 5  
Multilevel Analyses of the Effect of Mathematics Anxiety on Downstream Outcomes

Variable	Estimate	df	t	p	95% CI	
					LL	UL
Outcome: Demand appraisals						
Intercept	4.10	30.15	35.83	.000	3.86	4.33
AMAS Learn	0.24	418.21	2.55	.011	0.06	0.43
AMAS Eval	0.61	429.84	8.13	.000	0.47	0.76
Outcome: Resource appraisals						
Intercept	4.19	30.61	47.92	.000	4.01	4.36
AMAS Learn	-0.30	427.61	-3.08	.002	-0.49	-0.11
AMAS Eval	-0.53	404.02	-6.98	.000	-0.68	-0.38
Outcome: Cortisol change from baseline						
Intercept	-0.01	24.51	-0.23	.820	-0.11	0.09
AMAS Learn	0.05	343.88	0.92	.361	-0.06	0.16
AMAS Eval	-0.04	317.61	-0.92	.361	-0.13	0.05
Outcome: Testosterone change from baseline						
Intercept	0.01	21.46	0.17	.869	-0.06	0.08
AMAS Learn	-0.06	341.27	-1.30	.195	-0.14	0.03
AMAS Eval	-0.04	247.57	-1.23	.220	-0.11	0.03
Outcome: Exam performance						
Intercept	75.78	27.73	68.52	.000	73.51	78.05
AMAS Learn	-3.90	413.70	-3.79	.000	-5.93	-1.88
AMAS Eval	-2.74	418.22	-3.37	.001	-4.34	-1.14

Note. AMAS = Abbreviated Mathematics Anxiety Scale.

Table 6  
Multilevel Analyses of the Effect of Appraisals on Downstream Outcomes

Variable	Estimate	df	t	p	95% CI	
					LL	UL
Cortisol change from baseline						
Intercept	-0.01	23.33	-0.27	.792	-0.12	0.09
Resource	-0.02	342.90	-0.87	.387	-0.08	0.03
Demand	0.01	273.62	0.38	.704	-0.04	0.06
Testosterone change from baseline						
Intercept	0.00	22.23	0.12	.905	-0.07	0.07
Resource	0.08	337.84	3.69	.000	0.04	0.12
Demand	0.01	181.19	0.52	.604	-0.03	0.05
Exam performance						
Intercept	75.80	28.18	63.90	.000	73.37	78.23
Resource	3.19	421.09	6.85	.000	2.27	4.10
Demand	-1.84	422.72	-3.94	.000	-2.76	-0.92

on testosterone reactivity was not significant,  $\beta = 0.01$ ,  $SE = 0.01$ ,  $p = .230$ , 95% CI [-0.00, 03] (see Figure 1).

When mathematics evaluation anxiety was substituted as the main predictor, we again observed a significant indirect effect through resource appraisals on testosterone reactivity,  $\beta = -0.04$ ,  $SE = 0.01$ ,  $p = .007$ , 95% CI [-0.06, -0.01], but not through demand appraisals,  $\beta = 0.02$ ,  $SE = 0.01$ ,  $p = .182$ , 95% CI [-0.01, .05] (see Figure 2).

**Exam performance.** The effect of mathematics learning anxiety on exam performance was significantly mediated by both appraisals of resource,  $\beta = -0.92$ ,  $SE = 0.33$ ,  $p = .006$ , 95% CI [-1.64, -0.32], and demands,  $\beta = -0.42$ ,  $SE = 0.21$ ,  $p = .047$ , 95% CI [-0.91, -0.08] (see Figure 3). However, the direct effect of mathematics learning anxiety was still significant, suggesting partial mediation.

The association of mathematics evaluation anxiety on exam performance was also significantly mediated by both resource appraisals,  $\beta = -1.48$ ,  $SE = 0.35$ ,  $p < .001$ , 95% CI [-2.24, -0.86], and demand appraisals,  $\beta = -0.77$ ,  $SE = 0.31$ ,  $p = .012$ , 95% CI [-1.40, -0.22] (see Figure 4).

**Exploratory serial mediation.** Two exploratory three-step serial mediation models tested the following serial chain: mathematics anxieties ① resource appraisals ① change in testosterone ① exam performance. A limitation of the statistics program used (Hayes, 2013) is that only one predictor can be included at a time. Thus, one of the three-step model included learning anxiety as the main predictor (with evaluation as a covariate) and one model included evaluation anxiety as the main predictor (with learning anxiety as the covariate). The indirect effect of mathematics learning anxiety through resource appraisals and testosterone reactivity predicting exam performance was significant,  $\beta = -0.11$ ,  $SE = .07$ , 95% CI [-0.29, -0.02] (see Figure 5).

<sup>3</sup> This strategy was needed because MLMed can only accommodate one predictor at a time, and retaining the nested structure of the data was preferred to accommodating simultaneous predictors with non-nested models.

Table 7  
Multilevel Analyses of the Effect of Hormones on Exam Performance

Variable	Estimate	df	t	p	95% CI	
					LL	UL
Exam performance						
Intercept	76.12	29.91	65.35	.000	73.74	78.50
Cortisol reactivity	-3.39	342.77	-3.12	.002	-5.53	-1.26
Exam performance						
Intercept	76.14	30.68	65.97	.000	73.78	78.49
Testosterone reactivity	8.46	337.43	6.26	.000	5.81	11.12

The second three-step mediation model also yielded a significant indirect effect, with mathematics evaluation anxiety followed by resource appraisals, testosterone reactivity, and exam performance,  $\beta = -0.20$ ,  $SE = .09$ , 95% CI  $[-0.43, -0.06]$  (see Figure 6).

### General Discussion

This study examined relationships among mathematics anxiety, stress appraisals, neuroendocrine responses, and academic performance with the aim of elucidating the role stress processes play in mathematics anxiety's relationship with downstream outcomes. Results generally supported hypotheses: Higher levels of learning and evaluation anxiety predicted worse stress appraisals and lower exam scores. Importantly, appraisals emerged as potential mechanisms. That is, stress appraisals—resource appraisals in particular—partially mediated associations between mathematics anxiety, and neuroendocrine functioning and exam scores. Moreover, an exploratory serial mediation model suggested that the effects of resource appraisals on outcomes partially manifested via higher testosterone levels.

This research is the first to show a relationship between mathematics anxiety, stress appraisals, and neuroendocrine responses in a naturalistic classroom performance context. This research is also the first to examine stress appraisals as cognitive processes through which mathematics anxiety debilitates student achievement. As highlighted below, this innovation can inform theories from education and affective science to better understand factors that hamper student achievement and to develop successful interventions.

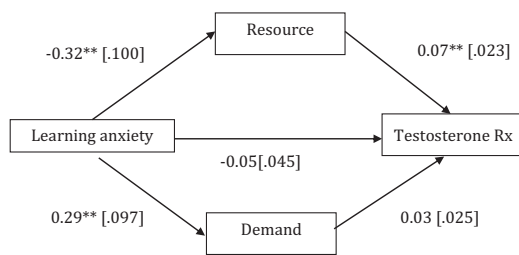


Figure 1. Stress appraisals as mediators of the association between mathematics learning anxiety and testosterone reactivity. Each coefficient is presented first, with standard errors in bracketed text. This model covaries for mathematics evaluation anxiety. \*\*  $p < .05$ .

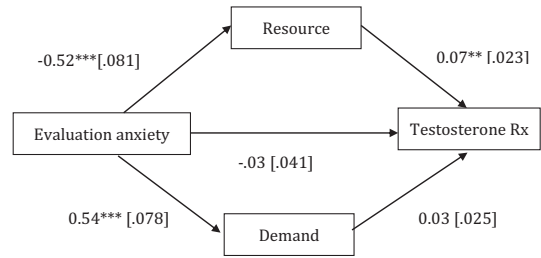


Figure 2. Stress appraisals as mediators of the association between mathematics evaluation anxiety and testosterone reactivity. Each coefficient is presented first, with standard errors in bracketed text. This model covaries for mathematics learning anxiety. \*\*  $p < .05$ . \*\*\*  $p < .001$ .

### Theoretical Implications

This research has implications for disruption models of mathematics anxiety, which posit that anxiety produces poor outcomes via cognitive processes (e.g., Pletzer, Kronbichler, Nuerk, & Kerschbaum, 2015; Ramirez et al., 2018). In addition to more widely studied working memory and affective processes (e.g., Maloney & Beilock, 2012; Ramirez et al., 2013), this research suggests stress appraisals play integral roles in the association between mathematics anxiety and poor outcomes in stressful contexts. The focus on stress appraisals as processes through which mathematics anxiety can relate to exam performance is important because of the ubiquity of stress in education. For instance, the United States (and many other) educational system uses high stakes tests as gateways to educational advancement (e.g., SAT/ACT, Graduate Record Examination, MCAT, LSAT). The higher students score on tests, the more opportunities they have. High stakes tests are inherently stressful—they present students with demands in the form of the exam, questions posed, and future implications—and students must marshal coping resources, including knowledge of the material, familiarity with the format, and social support factors, to perform. Thus, stress plays an important role in educational achievement (Schneider & Preckel, 2017). Understanding relationships between stress and other factors known to predict achievement (e.g., mathematics anxiety) is, therefore, an important focus for educational research.

This research also provides a nexus through which theories from educational science and the stress literatures can be integrated (cf., Jamieson & Elliot, 2018). The current study grounded hypotheses

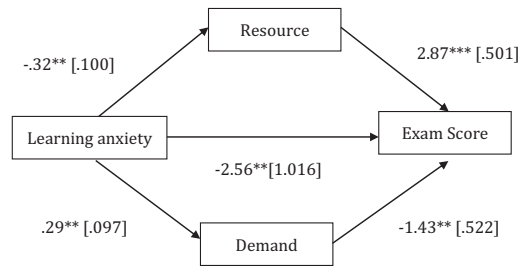


Figure 3. Stress appraisals as mediators of the association between mathematics learning anxiety and exam performance. Each coefficient is presented first, with standard errors in bracketed text. This model covaries for mathematics evaluation anxiety. \*\*  $p < .05$ . \*\*\*  $p < .001$ .

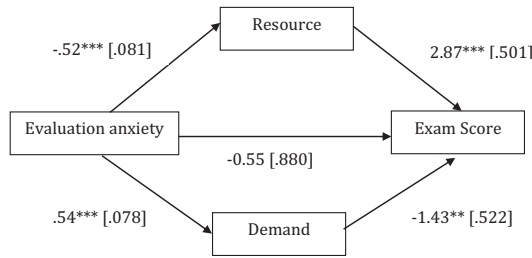


Figure 4. Stress appraisals as mediators of the association between mathematics evaluation anxiety and exam performance. Each coefficient is presented first, with standard errors in bracketed text. This model covaries for mathematics learning anxiety. \*\*  $p < .05$ . \*\*\*  $p < .001$ .

in the BPS model of challenge and threat (Jamieson et al., 2018), and then applied these concepts to understand psychological variables (i.e., mathematics anxiety) and settings (i.e., classroom performance contexts) from education science. This integration was seamless because of the focus of BPS models on “motivated performance” situations and the importance of stress in exam settings. More broadly, exploring how other theories may be bridged has the potential to stimulate new research and offer novel perspectives for understanding existing data (e.g., Yeager et al., 2016).

**Applied Implications**

In addition to informing theory, these data have relevance for student health and wellbeing. Most notably, neuroendocrine responses have potential consequences for health. Higher testosterone levels generally correlate with higher social status and more positive health outcomes in both males (e.g., Sapolsky, 1991) and females (Veiga, Viñuela, Cordero, Aparicio, & Polo, 2004). Moreover, lower testosterone levels predict negative health outcomes (Yeap, 2009). Specific to classroom exam situations, demonstrating that higher levels of mathematics anxiety and negative stress appraisals predicted lower testosterone levels suggests that mathematics anxious students may experience a form of social submission in such situations (e.g., Kraus & Mendes, 2014; Maner et al., 2008; Mazur et al., 1992). Social submission can then limit competitive behaviors, such as striving to perform well on exams. That is, if highly anxious students enter exams expecting failure, their body may respond to the expected loss of status/social defeat with neuroendocrine changes that reduce the chances for success. More long-term, adopting submissive responses can create health problems by impairing social relationships (Keltner, Young, & Buswell, 1997), in addition to the negative effects of poor performance.

Interestingly, and inconsistent with predictions, we observed no associations among mathematics anxiety, stress appraisals, and cortisol responses. This is an interesting pattern because cortisol is a commonly studied index of threat responses within challenge and threat theory (e.g., Blascovich, Vanman, Mendes, & Dickerson, 2011), and higher levels of mathematics anxiety have previously been associated with worse performance (Mattarella-Micke et al., 2011; Pletzer, Wood, Moeller, Nuerk, & Kerschbaum, 2010).

Combined the significant testosterone findings, this null pattern for cortisol insinuates the possibility that highly anxious students

experience anticipatory social defeat, which could lead to disengagement, thus dampening cortisol responses. That is, if highly anxious students enter mathematics exam contexts expecting defeat and preemptively “submit,” they may exhibit a response pattern akin to “learned helplessness” rather than active threat. This possibility may be especially likely in the community college sample here because of their higher incidence of prior failures relative to highly achieving students typical of research samples (Heine, 2005). More research, however, is needed to probe this unexpected pattern and explore dual-hormone effects in nontraditional samples.

Another applied contribution stems from the population and study context. Given the importance of community colleges in providing access to postsecondary education for members of low income and disadvantaged social groups, research on psychological factors that can act as roadblocks to achievement in these samples is integral. However, although community colleges account for almost half of all undergraduates (Shapiro, Dunder, Yuan, Harrell, & Wakhungu, 2014), there is a dearth of empirical research on psychological and biological factors in this population (Fong et al., 2016). Instead, research on demographic factors such as first-generation status and socioeconomic status have received more attention (e.g., Arbona & Nora, 2007; Crisp & Nora, 2010; Hawley & Harris, 2005). The current research highlights that a psychological process, mathematics anxiety, can predict achievement and neuroendocrine functioning.

Importantly for reducing mathematics anxiety, this research can inform interventions. For instance, *expressive writing*, or writing about one’s thoughts and feelings regarding stressors, reduced achievement gaps between high- and low-mathematics anxious students, and the use of words associated with affective experiences in the expressive writings positively predicted performance in highly anxious students (Park et al., 2014). Writing about one’s anxiety can thus reduce demands associated with rumination, and demand appraisals may be an avenue through which expressive writing improves outcomes. Alternatively, *stress reappraisal* manipulations seek to increase appraisals of resources by presenting stress responses as functional and helpful. Previous research has demonstrated this type of reappraisal exercise increases resources appraisals and attenuates mathematics anxiety (Jamieson et al., 2016). However, future work is needed that integrates existing interventions to address both “types” of stress appraisals—demands and resources—to maximize benefits for students (e.g., Rozek et al., 2019).

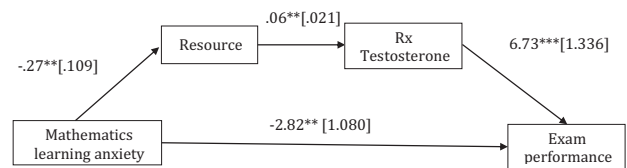


Figure 5. Serial mediation models with mathematics learning anxiety as the predictor. Each coefficient is presented first, with standard errors in bracketed text. The mathematics learning anxiety variable in this model covaries for mathematics evaluation anxiety. \*\*  $p < .05$ . \*\*\*  $p < .001$ .

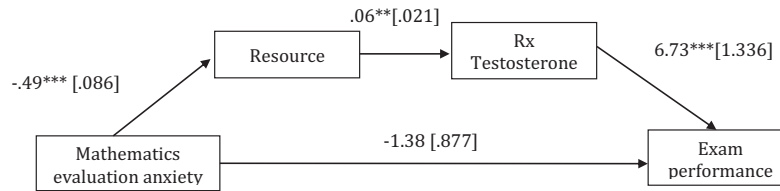


Figure 6. Serial mediation model with mathematics evaluation anxiety as the predictor. Each coefficient is presented first, with standard errors in bracketed text. The mathematics evaluation anxiety variable in this model covaries for mathematics learning anxiety. \*\*  $p < .05$ . \*\*\*  $p < .001$ .

## Limitations and Future Directions

Limitations need to be considered. First, although mathematics anxiety is thought to be stable (e.g., Ma & Xu, 2004), and although mediation models identified situation-specific stress appraisals as plausible mechanisms, the study was correlational in design. Myriad third variables could contribute to the observed pattern of effects. For instance, although this relationship did not emerge in the current study (see online supplemental material), previous research suggests implicit theories are associated with mathematics anxiety (e.g., Gunderson, Park, Maloney, Beilock, & Levine, 2018). Additional experimental work is needed to manipulate stress appraisals and measure effects on biological responses and downstream psychological processes to isolate stress appraisals as a mechanism.

The tight focus on BPS-derived stress appraisals afforded examination of the relationship between mathematics anxiety and these understudied stress processes, but additional insights can be gained from examining other cognitive processes known to associate with mathematics anxiety, such as executive processing and working memory (e.g., Beilock, 2008). For instance, interactions between stress appraisals and working memory processes can unfold in myriad ways. Working memory load may limit one's capacity to regulate stress responses, or negative stress responses could function as antecedents of working memory deficits (e.g., Schmader, Forbes, Zhang, & Mendes, 2009; Shields et al., 2017).

Academic performance was conceptualized as scores on a single exam (always the first exam). This limited approach suggests caution should be exercised when seeking to generalize results to broader academic performance outcomes, such as course retention rates, passing rates, or performance on other assignments completed outside of class. However, it was encouraging to observe a consistent pattern of relationships among mathematics anxiety, stress appraisals, physiological responses, and exam performance controlling for class cohort given that students from different cohorts completed exams constructed of different questions/topics and on different time schedules. Future research is needed, though, to test for robustness across contexts such as other assessments in mathematics courses or its role in predicting outcomes in nonmathematics STEM fields such as engineering or chemistry. Similarly, this research only collected data on students. We did not examine teacher's beliefs about mathematics anxiety and how those might inform community college students' beliefs and anxiety. Future work should explore those interpersonal associations in community college samples as prior research indicates teachers' mathematics anxiety is linked to lower student achievement.

Finally, recruiting community college students provided much needed data on this population, but the sample also limits generalizability. Relative to students from 4-year colleges, community college students are more likely to come from disadvantaged backgrounds and have generally perform more poorly compared to their 4-year college counterparts in secondary education settings (e.g., Ma & Baum, 2016). Moreover, adult learners, who comprise a sizable proportion of community college students, exhibit lower mathematics efficacy and higher mathematics anxiety compared to "traditional" (i.e., 4-year college) students. Future work testing mathematics anxiety and stress processes across multiple populations of students will help educators tailor programs to the needs of specific groups of students.

## Conclusion

Mathematics anxiety can harm student achievement in STEM domains (for a review see Ramirez et al., 2018). This research examined the interplay between mathematics anxiety, stress appraisals, neuroendocrine responses, and performance. Core findings demonstrated that stress appraisals may serve as mechanisms through which mathematics anxiety negatively predicts biological responses and classroom performance outcomes in stressful exam settings.

The mechanistic evidence provided by this research can inform the development of interventions aimed at attenuating mathematics anxiety and promoting achievement in STEM. Process-focused interventions that target mechanisms in specific contexts can be powerful tools to achieve lasting benefits (Yeager & Walton, 2011). Reducing mathematics anxiety or attenuating negative stress appraisals in understudied populations, such as community college students, can help students attain the STEM skills and training needed to thrive in a technological world.

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