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Math Anxiety, but Not Induced Stress, Is Associated With Objective Numeracy

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Many daily activities require a basic understanding of math. Numeracy, which refers to individual differences in the ability to understand numerical concepts and work with probabilities, has been linked to health-related decision-making and medical and financial outcomes. Whether affective influences impact numeracy has not been experimentally assessed, although research has shown that emotions impact judgments and decision-making. Stress is one commonly experienced affective influence that could impact numeracy. We examined whether objective and subjective numeracy were influenced by stress induced from anticipating giving a speech in a laboratory setting. We also examined the association of self-reported math anxiety, or apprehension pertaining to mathematics, with objective and subjective numeracy. Two experiments were conducted; the second was a direct replication. Undergraduate students (Experiment 1, $n = 99$; Experiment 2, $n = 139$) were randomly assigned to one of two conditions: a stress induction or a neutral condition. Whereas neither objective nor subjective numeracy significantly differed across conditions, math anxiety was a consistent predictor of objective and subjective numeracy. Math anxiety and baseline perceived stress did not consistently moderate any effects. These findings have implications for health care, educational, and financial contexts in which people must make decisions that involve complex numbers.

Public Significance Statement

People's ability to work with and interpret numbers correctly, or their numeracy, influences medical and financial decision-making and outcomes. In the present study, people with more math anxiety—that is, apprehension about math—performed worse on a numeracy measure and rated their numeracy as worse. Some participants were placed under stress, yet their numeracy was not impacted relative to participants who did not experience stress. This suggests that it may be worthwhile to test whether interventions that reduce math anxiety can improve health decision-making.

Keywords: stress, affect, numeracy, math anxiety, health

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Simple and complex numeric tasks are prevalent in daily life. Many daily activities rely on a basic understanding of mathematics, such as understanding the likelihood of side effects from medication, leaving a tip, and budgeting finances. Many of these numerical tasks involve a particular type of number: health and financial information is often presented as *rational numbers*, such as fractions, percentages, decimals, and ratios. For example, an adult concerned about their family history of diabetes could complete an online risk calculator for prediabetes and receive an estimate of their risk as 3 in 10 (or higher or lower; Centers for Disease Control and Prevention, n.d.). It is also often necessary to compare rational numbers to determine how to act: for example,

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one news article described the risk of sudden infant death syndrome as 1 in 16,400 when sharing a bed with one's infant versus 1 in 46,000 if the infant sleeps alone (Doucleff, 2018).

Research on the whole number bias (Alibali & Sidney, 2015; Ni & Zhou, 2005) has shown that adults may incorrectly think that 1 in 46,000 is larger than 1 in 16,400 because they only focus on the denominators. Adults' difficulties with rational numbers such as these are well-documented (Alibali & Sidney, 2015; DeWolf, Grounds, Bassok, & Holyoak, 2014; Ma, 1999; Ni & Zhou, 2005). People often have lower ability to work with fractions than with other types of numbers (Opfer & DeVries, 2008; Reyna & Brainerd, 2008), and people have less positive attitudes about rational numbers, like fractions, than about other types of numbers, like whole numbers, percentages, and math in general (Sidney, Thompson, Fitzsimmons, & Taber, 2019). Thus, adults must often interpret and solve problems containing numbers that they find difficult and do not like. Here, we tested whether stress affected people's ability to accurately reason with rational numbers. This research has implications for understanding the conditions under which adults comprehend this type of numeric information.

The Construct of Numeracy

It is crucial to understand when and why people accurately interpret numeric information involving rational numbers given their prevalence and importance. In the health decision-making literature, *numeracy* refers to the cognitive ability to understand numerical concepts and work with basic probabilities (Peters, Lipkus, & Diefenbach, 2006). *Objective numeracy* is assessed as performance on math problems (Lipkus, Samsa, & Rimer, 2001; Schwartz, Woloshin, Black, & Welch, 1997; Weller et al., 2013). *Subjective numeracy* is assessed as perceived ability and preferences for dealing with numbers (Fagerlin et al., 2007). Subjective numeracy measures were initially developed as a proxy for objective numeracy because participants disliked objective numeracy scales that felt like taking aptitude tests (Fagerlin et al., 2007). Although they are positively associated, objective and subjective numeracy are now considered to be distinct (Liberali, Reyna, Furlan, Stein, & Pardo, 2012; Peters & Bjalkebring, 2015; Waters et al., 2018) and interact to predict health and financial outcomes (Peters et al., 2019).

Multiple reviews have detailed the associations of low numeracy with worse medical and health-related decisions and outcomes (Lipkus & Peters, 2009; Nelson, Reyna, Fagerlin, Lipkus, & Peters, 2008; Peters, 2012; Reyna & Brainerd, 2007; Reyna, Nelson, Han, & Dieckmann, 2009). We highlight some of the associations here. In general, people lower in numeracy are more susceptible to making decisions based on factors unrelated to the numerical information such as emotion, affect, framing effects, and other biases (Reyna et al., 2009). With respect to health more broadly, lower numeracy is associated with a host of negative health-related outcomes. These negative outcomes include greater body mass index (Huizinga, Beech, Cavanaugh, Elasy, & Rothman, 2008); higher prevalence of comorbidities, having more prescription medications, and rating one's physical and mental health as worse (Garcia-Retamero, Andrade, Sharit, & Ruiz, 2015); and longer delays in seeking medical care following symptoms of acute coronary syndromes (Petrova et al., 2017). Compared to people higher in numeracy, people lower in numeracy were less satisfied with their current role in health decision-making such that they preferred to play a more passive role (Galesic & Garcia-Retamero, 2011). With respect to health-related judgments, people with lower numeracy assessed risk less accurately following information about reduced risk conferred by mammography (Schwartz et al., 1997), comprehended information about health screening less accurately (Petrova, Garcia-Retamero, Catena, & van der Pligt, 2016), attached less appropriate emotional meaning to different risk magnitudes (Petrova, van der Pligt, & Garcia-Retamero, 2014), ignored the denominator more often when making judgments about risk (Garcia-Retamero & Galesic, 2009), and used decision-making strategies less flexibly (Traczyk et al., 2018). Lower numeracy is also associated with worse financial outcomes (Peters et al., 2019).

Thus, it is clear that numeracy itself is associated with important outcomes. Here, we sought to identify what we conceptualized as precursors to better or worse numeracy. These identified factors could be targeted in future interventions (e.g., to reduce math anxiety), or situations could be modified to reduce these factors (e.g., stress) to facilitate better numeracy and subsequent decision-making.

Does Numeracy Fluctuate From Moment to Moment?

In the health decision-making literature, numeracy—and performance on the one-time, brief measures used to assess numeracy—is conceptualized as an individual difference (e.g., Cokely, Galesic, Schulz, Ghazal, & Garcia-Retamero, 2012; Liberali et al., 2012; Weller et al., 2013). Consistent with this perspective, math cognition research has indicated that individuals likely have an underlying "number sense" that has developed across their life span (Halberda, Ly, Wilmer, Naiman, & Germine, 2012). However, assessing accuracy on a math task—regardless of whether a "numeracy" or different measure is used—is always a measure of performance at a given moment. There is variability in cognitive performance from trial to trial (Siegler, 1996, 2007); even slight changes in the stimuli used to assess mathematical ability can influence performance (Braithwaite & Siegler, 2018). Given that subtle changes in stimuli can elicit noticeable changes in math performance, we predicted that numeracy—as assessed with standard scales (Fagerlin et al., 2007; Weller et al., 2013) used in the health decision-making literature—would differ for participants who were placed under stress relative to those who were not.

Stress May Impact Numeracy

One factor that might cause moment-to-moment fluctuations in numeracy is changes in affect and emotion. Emotions have a major impact on interpretation, reasoning, judgment, and decision-making (Blanchette & Richards, 2010; Lerner, Li, Valdesolo, & Kassam, 2015; Peters, Västfjäll, et al., 2006; Västfjäll et al., 2016). In the present study, we focused on stress—for applied and conceptual reasons—as an affective influence that could impact numeracy. Stress can be defined as a state in which a person appraises their environment as taxing or exceeding their current resources (Lazarus & Folkman, 1984). From an applied perspective, individuals may be presented with numeric information during periods of stress. For example, receiving information about disease risk may be stressful if the information confers bad news (Bennett et al., 2008). Stress may also arise from events unrelated to the task at hand; for example, a parent who is wrangling small children while trying to comprehend numeric health information during a doctor's appointment may experience stress. If stress does impact numeracy, it may be important to minimize stressful experiences as much as possible while people receive numeric information. Thus, understanding whether stress impacts numeracy has practical implications for identifying optimal conditions for risk communication.

Despite the high likelihood that people will sometimes be presented with numeric information while feeling stressed, little research has focused on whether stress influences either objective or subjective numeracy. From a conceptual perspective, physiological stress responses, including cortisol production, impair cognitive processes (Schmader, Johns, & Forbes, 2008). A review found that stress induced in a laboratory often impaired decision-making; proposed mechanisms included decreased attention and executive functioning (Starcke & Brand, 2012). Higher stress levels are associated with lower performance on a complex arithmetic task (Beilock, 2008) and lower performance on measures of working memory capacity (Blanchette & Richards, 2010; Moran, 2016). Working memory is critical for math performance, especially for multistep problems requiring complex calculations and holding and updating numeric information in memory (Ashcraft & Krause, 2007). Further, highly competent adults sometimes "choke under pressure" (e.g., Beilock & Carr, 2005) when solving complex math problems and rely on simpler, less effective, strategies during high-pressure situations (Beilock & DeCaro, 2007). An increased stress response is also one mechanism through which negative stereotypes (i.e., women are bad at math) may impair numeracy (Schmader et al., 2008; Spencer, Logel, & Davies, 2016). Based on these findings, if people experience stress while faced with numeric information, they may interpret the information less accurately and subsequently make worse decisions based on their inaccurate interpretation.

Our primary hypothesis regarding the effect of stress on numeracy was based on objective numeracy. However, we also included subjective numeracy as a primary outcome because subjective and objective numeracy are positively correlated (e.g., Fagerlin et al., 2007; Peters & Bjalkebring, 2015; Peters et al., 2017). Further, it is unknown whether subjective numeracy is stable "across time and context" (Peters & Bjalkebring, 2015, p. 815), and research is needed to test whether manipulations of "general mood state[s]" alter subjective numeracy (Peters & Bjalkebring, 2015, p. 813).

Stress Measurement

Stress can be assessed in multiple ways, including physiological assessments and self-reported daily hassles and stressful life events (Kanner, Coyne, Schaefer, & Lazarus, 1981). However, stressful events that naturally occur in daily life are difficult to manipulate, which obviates the possibility of determining causality. Thus, to determine the causal impact of stress, we adopted an induction technique previously used to induce stress in which participants were asked to prepare a speech that would be videotaped (Tugade & Fredrickson, 2004; Yip & Côté, 2013). Despite potential differences in the degree of stress experienced from stressful life events or daily hassles versus stress induced in the laboratory, we had no reason to expect that different types of non-math-related stressors would differentially impact numeracy.

Math Anxiety May Impact Numeracy

We also examined affect related to math tasks themselves. Math anxiety refers to tension, apprehension, or fear that interferes with math performance (Ashcraft, 2002) and results from the mathematical task at hand. People who are highly math-anxious tend to avoid math (Ashcraft, 2002; Hembree, 1990), and avoiding numeric information in the moment or not taking math-related classes are mechanisms through which math anxiety could lead to lower numeracy. Anxiety about math and stress unrelated to math may influence numeracy for the same reason: interference with working memory may limit cognitive resources to perform optimally. In prior studies, adults and children higher in math anxiety showed worse performance on math tasks in neutral and health contexts (Sidney, Thalluri, Buerke, & Thompson, 2019; Sidney, Thompson, et al., 2019; Vukovic, Kieffer, Bailey, & Harari, 2013), and math anxiety has been correlated with lower objective numeracy (Rolison, Morsanyi, & O'Connor, 2016).

In addition to objective numeracy, we examined whether math anxiety was associated with subjective numeracy. A common subjective numeracy scale (and the one used in the present study; Fagerlin et al., 2007) assesses participants' perceived ability with numeric information and their preferences for how numbers are presented. In prior research, math anxiety has been associated with a variety of constructs that are conceptually similar to perceived math ability (for a review of math anxiety, see Ashcraft, 2002). More specifically, participants with greater math anxiety reported lower subjective numeracy (Peters et al., 2017), lower math self-efficacy (McMullan, Jones, & Lea, 2012; Pajares & Urdan, 1996; Silk & Parrott, 2014) and ability (Meece, Wigfield, & Eccles, 1990), lower confidence about performance on specific math problems (Morsanyi, Busdraghi, & Primi, 2014; Rolison et al., 2016), and less positive emotions (Peters & Bjalkebring, 2015) and attitudes about math (Sidney, Thompson, et al., 2019). Further, to the extent that objective and subjective numeracy are associated, then math anxiety should be associated with both.

Current Experiments and Hypotheses

We conducted two experiments—the second a direct replication—to test the hypothesis that greater stress would lead to lower numeracy, operationalized as performance on two common measures (Fagerlin et al., 2007; Weller et al., 2013). Importantly, several items in common numeracy scales, such as the Rasch-Based Numeracy Scale assessing objective numeracy (Weller et al., 2013) and the Subjective Numeracy Scale (Fagerlin et al., 2007), assess people's ability and preferences for rational numbers, such as fractions. As noted earlier, rational numbers are difficult and disliked by adults yet are frequently encountered in health-related decisions.

In addition to our primary hypotheses, we tested whether any negative effects of the stress induction were exacerbated by higher levels of individual differences in two related constructs: math anxiety and baseline levels of perceived stress. Finally, we explored relationships between stress, numeracy, and gender given prior research demonstrating that women score lower than men on objective numeracy scales (Galesic & Garcia-Retamero, 2010) and have differential attitudes about math. For instance, even among women and men who were equally mathematically competent with fractions, women liked fractions less (Sidney, Thompson, et al., 2019). Further, research on stereotype threat has indicated that women's math performance often suffers when they are exposed to negative stereotypes about women's math ability (Nguyen & Ryan, 2008; Picho, Rodriguez, & Finnie, 2013; Spencer, Steele, & Quinn, 1999; Walton & Spencer, 2009; but see Stoet & Geary, 2012 for challenges to this theoretical framework and Spencer et al., 2016 for additional discussion), which may contribute to gender differences in numeracy (Peters & Bjalkebring, 2015). These performance differences could be further exacerbated by induced stress.

General Method

Overview

Two studies were conducted with nearly identical methodology. Data from Experiment 1 were collected and preliminarily analyzed from August to December 2017. We conducted Experiment 2 from January to May 2018 as a direct replication for two reasons. First, we sought to determine whether the null effects obtained in the first study were replicated in a second sample. Second, we sought to recruit a greater proportion of male participants because using a psychology participant pool to collect data resulted in a sample that was 89% female for Experiment 1. The procedure and measures of both studies were identical except for one minor change to the math anxiety item, described in Experiment 2.

Design and Procedure

Participants were randomly assigned to one of two conditions in which we manipulated affect (the experimental stress condition vs. the neutral control condition). Up to four participants completed the study at once, and participants could not see other's computer screens. Participants were informed that they would be completing measures for two separate studies. They were told that the first study was about decision-making and involved random assignment to one of two tasks and that the second study was about how people think about numbers. Following these instructions, participants provided informed consent.

Participants first completed the baseline survey. Next, participants completed an established stress induction that we adapted to run multiple participants in both conditions at once (Tugade & Fredrickson, 2004; Yip & Côté, 2013). Participants in the stress condition were informed that they had 60 s to mentally prepare a 3-min speech on "why you are a good candidate for your ideal job" that would be video-recorded and evaluated by their peers. In reality, participants did not give a speech. In the neutral condition, participants had 60 s to make a grocery list. Participants then completed the postmanipulation survey, were told that they would not give a speech if in the stress condition, watched a funny clip from *The Office* to improve their mood (Gilman et al., 2017), and reported mood a final time to ensure that mood was restored.

Measures

All measures were administered in the order in which they are described. Some demographic items (i.e., year in school, marital status, religious affiliation, current employment) were collected but not reported. We collected data from a one-item decision-making task in which participants chose between hypothetical bowls with different numbers of "winning" red jellybeans (Bowl 1: one red jellybean and nine white jellybeans; Bowl 2: nine red jellybeans and 91 white jellybeans; adapted from Denes-Raj and Epstein, 1994 and Peters, Västfjäll, et al., 2006). However, differences in how this item was recreated (e.g., lacking a visual representation, lack of randomization of the order in which choices were presented) made interpretation difficult, so we do not discuss this item further. Additionally, several items assessing preferences for shared decision-making, awareness of and interest in receiving genetic test results, and trust in information from different sources were included after the dependent variables described here but are not central to our hypotheses and are not discussed further.

Baseline survey. Measures described in this section were administered prior to the stress induction. In Experiment 1, baseline math anxiety was assessed with "How anxious are you about math?" (adapted from Ashcraft, 2002) on a 5-point scale from 1 (*not at all anxious*) to 5 (*extremely anxious*). This modified wording was used to improve clarity. According to Ashcraft's (2002) seminal review paper on math anxiety, this single-item measure was correlated from .49 to .85 with scores on an abbreviated version of the original 98-item Mathematics Anxiety Rating Scale created by Richardson and Suinn (1972). Ashcraft states that the one-item measure is sufficient "for a quick determination" of math anxiety (Ashcraft, 2002, p. 181). Here, the math anxiety item was displayed among five randomized education-related filler items written for this study (e.g., "How many hours do you typically spend preparing for an exam?").

The Perceived Stress Scale (Cohen, Kamarck, & Mermelstein, 1983) was used to account for individual differences in stress levels at baseline. This 10-item scale included questions about participants' feelings and thoughts during the last month (e.g., "How often have you been upset because of something that happened unexpectedly?") on a scale ranging from 0 (*never*) to 4 (*very often*). Items were reverse coded if necessary and then averaged (Experiment 1, $\alpha = .88$; Experiment 2, $\alpha = .84$).

Neuroticism (Donnellan, Oswald, Baird, & Lucas, 2006) was included to covary the effects of individual differences in negative emotion from the effects of induced stress. Participants were asked to indicate the accuracy of four statements assessing neuroticism as descriptors of themselves (e.g., "have frequent mood swings") on a scale from 1 (*very inaccurate*) to 5 (*very accurate*). One item was reverse coded, and because "seldom feel blue" produced a lower alpha, it was excluded. The three remaining items were averaged (Experiment 1, $\alpha = .77$; Experiment 2, $\alpha = .61$).

Postmanipulation survey. Measures described in this section were administered after the stress induction. To serve as a manipulation check, participants' stress levels were assessed immediately after the stress induction. Participants rated the extent to which they felt 15 emotions "currently (that is, right now)" (Tugade & Fredrickson, 2004; see also Yip & Côté, 2013) on scales from 1 (*strongly disagree*) to 7 (*strongly agree*). Scores from the items "anxious," "tense," and "nervous" were averaged to create an overall stress score (the decision to examine only these three items was made a priori and was based on the approach taken in previous literature; Experiment 1, α = .93; Experiment 2, α = .88; Raghunathan & Pham, 1999).

Subjective numeracy was assessed with the eight-item Subjective Numeracy Scale (Fagerlin et al., 2007). Four items, on a scale from 1 (*not at all good*) to 6 (*extremely good*), assessed self-perceived ability to perform mathematical operations (e.g., "How good are you at working with fractions?"). The remaining four questions assessed, on 6-point scales, how individuals prefer numbers to be presented (e.g., "When reading the newspaper, how helpful do you find tables and graphs that are parts of a story?"). One item regarding weather forecasts was reverse coded, and then remaining items were averaged (Experiment 1, α = .78; Experiment 2, α = .76).

Objective numeracy was assessed with the Rasch-Based Numeracy Scale (Weller et al., 2013). Participants were presented with eight story problems that involved probabilistic reasoning and/or calculations with rational numbers when solved correctly (e.g., finding 10% of 1,000). Objective numeracy scores were the sum of correct responses (range = 0 to 8). The scale was designed to include items of greater difficulty than older numeracy measures, was validated in a sample with a range of ages and educational attainment, predicts decision-making preferences and risk judgments (Weller et al., 2013), and is distinct from general intelligence (Peters & Bjalkebring, 2015).

Background demographic information about age, sex (coded as 1 = male, 0 = female), and race/ethnicity (coded as 1 = non-Hispanic White, 0 = not non-Hispanic White) was collected. To determine effort on the Objective Numeracy Scale on a scale from 1 (*zero effort*) to 6 (*extreme effort*), participants were asked, "Overall, how much effort did you use to answer the previous set of questions that asked you to solve math problems?" Finally, we probed for suspicion about the deception. Participants were excluded from analyses if they reported being suspicious of the stress induction on any of four open-ended questions (e.g., "Do you think there may have been more to the study than meets the eye? If yes, how so?").

Overview of Analyses

Data on variables analyzed here, analysis syntax, survey items, and the protocol and experimenter script are available on Open Science Framework: https://osf.io/zuenc/?view_only=67722abaf80a4c3bbcf634e21c8061d8. The same series of analyses was conducted for both experiments. This meant that decisions made about covariates that were based on Experiment 2 were also applied to data analysis for Experiment 1 (we examined bivariate associations in both experiments to determine covariates, and there were more significant associations in Experiment 2 than in Experiment 1). We first examined the success of the stress manipulation by conducting a *t* test to compare stress levels postinduction across conditions. We next examined the success of the randomization by testing whether baseline and demographic measures differed across conditions. Then, we examined correlations among all study measures. Baseline and demographic measures that were correlated with subjective numeracy, objective numeracy, or induced stress in either experiment were selected for inclusion as covariates in subsequent analyses in both experiments.

Our primary analyses were unadjusted analyses testing whether objective and subjective numeracy differed across stress conditions. We then conducted hierarchical linear regressions controlling for baseline and demographic factors (Step 1) to test whether the stress condition (Step 2) predicted objective and subjective numeracy. We also conducted parallel linear regression analyses testing whether induced stress levels predicted objective and subjective numeracy, as well as unadjusted analyses with induced stress level as a predictor. A linear regression was also conducted to assess whether subjective numeracy was a significant predictor of objective numeracy. We next tested whether baseline math anxiety and baseline perceived stress moderated the association between condition and objective numeracy and subjective numeracy (controlling for the same set of covariates used in the primary analyses) using hierarchical linear regressions (covariates entered on Step 1, main effects on Step 2, interaction on Step 3). Math anxiety and perceived stress were mean-centered prior to creation of interaction terms. All the analyses described thus far were conducted in SPSS Statistics Version 25. We conducted post hoc equivalence tests on the differences in numeracy across conditions using the *R* package TOSTER (Lakens, 2017b). Finally, we conducted a continuously cumulating meta-analysis for the primary analyses (*t* tests examining differences in objective and subjective numeracy by condition) using supplemental material provided by Braver, Thoemmes, and Rosenthal (2014).

Experiment 1

Participants

This research was approved by Kent State University's institutional review board. Participants (*N* = 99) were undergraduates who were recruited through a psychology participant pool and compensated with course credit. The sample size for Experiment 1 was based on an a priori power analysis conducted in G*Power (Faul, Erdfelder, Lang, & Buchner, 2007), which indicated that a sample size of 102 would yield 80% power to detect differences across two groups using a one-tailed *t* test with a medium effect size (Cohen's *d* = 0.50) with α = .05 and a 1:1 allocation ratio. The one-tailed *t* test was selected to test the hypotheses that objective and subjective numeracy would be *lower* in the stress condition. We stopped data collection at 105 total participants because we believed we had reached our target sample size of 102 respondents with usable data. However, we coded three additional people as expressing suspicion and excluded their data after stopping data collection. This resulted in an analytic sample size of 99 after excluding six participants total, all for being suspicious of some aspect of the deception. Post hoc power analyses indicated that a sample of 99 participants provided 80% power to detect an effect size of Cohen's *d* = .50 using one-tailed *t* tests and 69% power using two-tailed *t* tests. Thus, the final sample in Experiment 1 was somewhat underpowered for a two-tailed *t* test as a sample size of 128 would be required to achieve 80% power for a two-tailed *t* test.

Most participants (*N* = 99) were female (88.9%) with an average age of 19.18 years (*SD* = 1.76; range = 18 to 28). Most participants (79.6%) identified as non-Hispanic White, with 8.1% Black or African American, 5.1% Asian or Asian American, 1.0% Hispanic or Latino/a, and 5.1% of mixed or other racial background. One participant did not report their race. There were no other missing data. The six excluded participants were higher in objective numeracy, $M = 5.00$, and reported putting forth more effort, $M = 4.33$, than the 99 retained in analyses, objective numeracy: $M = 3.64$, $t(103) = -2.00$, $p = .048$; effort: $M = 3.43$, $t(103) = -2.05$, $p = .043$, with no differences on any other study variables (i.e., math anxiety, perceived stress, neuroticism, subjective numeracy, objective numeracy, effort on objective numeracy, induced stress, age, gender, race/ethnicity, or emotion induction condition; all $ps > .05$). Results did not change when these six participants were retained in analyses.

Results and Discussion

Manipulation check. As expected, participants in the stress condition reported significantly greater stress, $M = 4.39$, than participants in the neutral condition, $M = 2.61$. This confirmed that the stress induction was successful (Table 1). Condition remained a significant predictor of induced stress, $B = 1.71$, $SE\ B = 0.29$, $\beta = 0.47$, $p < .001$, 95% CI [1.12, 2.29], when gender, math anxiety, baseline perceived stress, and neuroticism were entered on a previous step in a regression analysis.

Differences in demographic factors, baseline variables, and effort by condition. Confirming successful randomization, we found no significant differences in baseline levels of math anxiety, perceived stress, or neuroticism across condition (Table 1). There were no significant differences in age, gender, or race/ethnicity across conditions (Table 1). Also, self-reported effort on the Rasch-Based Numeracy Scale—assessed after the manipulation—did not differ across conditions (Table 1).

Associations among variables. Table 2 provides correlations among study variables. Consistent with prior research, objective and subjective numeracy were moderately associated ($r = .50$). This suggests that objective and subjective numeracy are related but distinct.

Before testing the primary hypotheses, we examined whether objective and subjective numeracy and induced stress levels were associated with baseline variables and with the demographic factors of age, gender, and race/ethnicity. Participants with higher baseline math anxiety subsequently had lower objective, $r(97) = -0.29$, $p < .001$, and subjective numeracy, $r(97) =$

Table 1
Unadjusted Means and Standard Deviations of Study Variables Across Emotion Induction Conditions

Variable	Stress *M* (*SD*) (*n* = 48)	Control *M* (*SD*) (*n* = 51)	*t*	*df*	*p*	95% CI
Experiment 1						
Age	18.92 (1.11)	19.43 (2.19)	1.49	74.9	.141	[−0.18, 1.21]
Baseline math anxiety	2.92 (1.22)	2.88 (1.24)	−0.14	97	.890	[−0.53, 0.46]
Baseline perceived stress	2.83 (0.67)	2.77 (0.70)	−0.45	97	.651	[−0.34, 0.21]
Neuroticism	2.77 (0.99)	2.70 (0.98)	−0.36	97	.719	[−0.47, 0.32]
Induced stress	4.39 (1.68)	2.61 (1.51)	−5.54	97	<.001	[−2.41, −1.14]
Subjective numeracy	3.57 (0.89)	3.85 (0.89)	1.57	97	.120	[−0.07, 0.64]
Objective numeracy	3.52 (1.56)	3.75 (1.64)	0.70	97	.487	[−0.41, 0.86]
Effort	3.46 (0.97)	3.41 (1.13)	−0.22	97	.827	[−0.47, 0.38]
	Stress, % (*n*)	Control, % (*n*)	χ^2	*df*	*p*	
Male	10.4	11.8	0.05	1	.831	
Non-Hispanic White	80.9	80.4	0.003	1	.954	
Experiment 2						
	Stress *M* (*SD*) (*n* = 69)	Control *M* (*SD*) (*n* = 70)	*t*	*df*	*p*	95% CI
Age	19.6 (1.40)	19.6 (1.52)	−0.09	137	.928	[−0.51, 0.47]
Baseline math anxiety	6.08 (2.53)	5.91 (2.21)	−0.40	132	.690	[−0.98, 0.65]
Baseline perceived stress	2.77 (0.61)	2.78 (0.59)	0.10	137	.918	[−0.19, 0.21]
Neuroticism	2.66 (0.88)	2.69 (0.86)	0.23	137	.821	[−0.26, 0.33]
Induced stress	3.74 (1.69)	2.81 (1.32)	−3.60	128.4	<.001	[−1.43, −0.42]
Subjective numeracy	3.66 (0.98)	3.83 (0.83)	1.08	137	.284	[−0.14, 0.47]
Objective numeracy	3.97 (1.64)	4.13 (1.63)	0.57	137	.571	[−0.14, 0.47]
Effort	3.39 (1.03)	3.41 (1.08)	0.13	137	.898	[−0.39, 0.71]
	Stress, % (*n*)	Control, % (*n*)	χ^2	*df*	*p*	
Male	24.6	40.0	3.75	1	.053	
Non-Hispanic White	73.9	76.8	0.16	1	.693	

Table 2
Correlations Among Study Variables

Variable	1	2	3	4	5	6	7	8	9	10
Demographic										
1. Age	—	0.11	−0.09	0.004	−0.03	−0.08	−0.10	0.02	0.07	−0.11
2. Gender[a]	0.10	—	−0.07	0.003	−0.08	−0.20*	−0.12	0.13	0.04	−0.06
3. Race/ethnicity[b]	−0.05	−0.01	—	0.02	−0.07	0.09	−0.15	−0.05	0.04	−0.15
Baseline										
4. Math anxiety	−0.10	−0.11	0.08	—	0.11	0.01	0.04	−0.37**	−0.36**	−0.09
5. Perceived stress	0.004	−0.26**	−0.07	0.13	—	0.56**	0.38**	0.06	0.17	−0.08
6. Neuroticism	−0.06	−0.36**	0.003	0.12	0.72**	—	0.34**	0.17	0.19	−0.12
Postmanipulation										
7. Induced stress	−0.11	−0.17*	0.12	0.02	0.37**	0.34**	—	0.04	0.15	0.03
8. Subjective numeracy	0.002	0.27**	0.03	−0.42**	−0.03	−0.08	0.02	—	0.50**	0.10
9. Objective numeracy	−0.06	0.26**	0.05	−0.29**	0.03	−0.05	0.10	0.53**	—	−0.07
10. Effort on objective numeracy task	−0.10	−0.09	0.03	0.04	−0.06	−0.05	0.16	0.01	−0.01	—

Note. Experiment 1 is above the diagonal; Experiment 2 is below the diagonal.
[a] Male = 1, female = 0. [b] Non-Hispanic White = 1, not non-Hispanic White = 0.
* $p < .05$. ** $p < .01$.

−0.42, $p < .001$, assessed after the manipulation. Those who reported greater perceived stress at baseline, $r(97) = 0.37$, $p < .001$, and greater neuroticism, $r(97) = 0.34$, $p < .001$, subsequently reported higher induced stress following the manipulation (Table 2). Neither baseline perceived stress nor neuroticism was significantly associated with objective or subjective numeracy (Table 2).

With respect to demographic variables, age was not significantly associated with any of the three postmanipulation variables (i.e., objective numeracy, subjective numeracy, induced stress; Table 2). Similarly, the three postmanipulation variables of objective numeracy, subjective numeracy, and induced stress did not differ as a function of race/ethnicity or gender. Specifically, objective numeracy did not differ by race/ethnicity, $t(96) = -0.42$, $p = .676$, 95% CI [−0.97, 0.63], or gender, $t(97) = -0.40$, $p = .690$, 95% CI [−1.22, 0.81]; subjective numeracy did not differ by race/ethnicity, $t(96) = 0.60$, $p = .596$, 95% CI [−0.34, 0.58], or gender, $t(97) = -1.26$, $p = .211$, 95% CI [−0.93, 0.21]; and induced stress did not differ by race/ethnicity, $t(96) = 1.46$, $p = .147$, 95% CI [−0.24, 1.59], or gender, $t(97) = 1.22$, $p = .227$, 95% CI [−0.45, 1.86].

Primary analyses: Predictors of numeracy. Contrary to hypotheses, neither objective nor subjective numeracy significantly differed across conditions (Table 1). In these unadjusted analyses, Cohen's *d* was 0.10 for objective numeracy and 0.19 for subjective numeracy. To further test whether condition was a significant predictor of objective numeracy and subjective numeracy, we conducted separate linear regressions controlling for a set of four covariates (i.e., math anxiety, baseline perceived stress, neuroticism, and gender) as each of these variables was associated with subjective numeracy, objective numeracy, or induced stress in Experiment 2, and we sought to conduct parallel analyses across experiments. These analyses revealed the same pattern of results as the unadjusted analyses: condition did not significantly predict either outcome (Table 3). However, those with greater baseline math anxiety had lower objective and subjective numeracy. Due to variability in induced stress within the stress condition (i.e., the stress induction was not equally effective for all participants), we

Table 3
Results of Two Hierarchical Linear Regression Analyses With Emotion Induction Condition Predicting Objective Numeracy and Subjective Numeracy, Controlling for Gender, Baseline Math Anxiety, Baseline Perceived Stress, and Neuroticism

	Objective numeracy					Subjective numeracy				
Variable	*B*	*SE B*	β	95% CI	*p*	*B*	*SE B*	β	95% CI	*p*
Experiment 1										
Gender	0.39	0.48	0.08	[−0.56, 1.34]	.42	0.47	0.27	0.17	[−0.05, 1.00]	.078
Baseline math anxiety	−0.50	0.12	−0.38	[−0.74, −0.25]	<.001	−0.27	0.07	−0.37	[−0.41, −0.14]	<.001
Baseline perceived stress	0.33	0.26	0.14	[−0.19, 0.86]	.21	−0.01	0.15	−0.01	[−0.30, 0.28]	.959
Neuroticism	0.21	0.19	0.13	[−0.16, 0.58]	.26	0.20	0.10	0.21	[−0.01, 0.40]	.061
Emotion induction condition	−0.24	0.30	−0.08	[−0.83, 0.35]	.42	−0.28	0.16	−0.16	[−0.60, 0.05]	.092
Experiment 2										
Gender	3.73	0.74	0.31	[0.46, 1.66]	.001	0.46	0.17	0.23	[0.13, 0.78]	.007
Baseline math anxiety	−0.18	0.06	−0.27	[−0.29, −0.08]	.001	−0.16	0.03	−0.40	[−0.22, −0.10]	<.001
Baseline perceived stress	0.42	0.31	0.16	[−0.20, 1.03]	.183	0.14	0.17	0.10	[−0.19, 0.48]	.401
Neuroticism	−0.02	0.22	−0.01	[−0.46, 0.42]	.935	−0.12	0.12	−0.02	[−0.26, 0.23]	.901
Emotion induction condition	−0.05	0.26	−0.02	[−0.57, 0.47]	.837	−0.08	0.14	−0.05	[−0.37, 0.23]	.568

Note. *SE* = standard error; CI = confidence interval. Emotion induction condition coded as stress = 1, neutral control = 0. Experiment 1: objective numeracy, $R^2 = 0.20$; subjective numeracy, $R^2 = 0.22$. Experiment 2: objective numeracy, $R^2 = 0.18$; subjective numeracy, $R^2 = 0.23$.

conducted parallel regression analyses in which we replaced condition with induced stress as a continuous predictor. The pattern of significant results was the same as when condition was entered as the predictor for both objective and subjective numeracy (see Supplemental Table 1 for a summary). Thus, across all analyses, there was no statistically significant evidence that induced stress affected numeracy.

We also included subjective numeracy as a predictor of objective numeracy given that the two measures were correlated. Subjective numeracy was a significant predictor of objective numeracy, $B = 0.71$, $SE\ B = 0.17$, $\beta = 0.40$, $p < .001$, 95% CI [0.37, 1.06]. Lower math anxiety remained a significant predictor of objective numeracy, $B = -0.30$, $SE\ B = 0.12$, $\beta = -0.23$, $p = .015$, 95% CI [−0.54, −0.06].

Moderator analyses. We next tested whether baseline math anxiety and baseline perceived stress moderated the association between condition and objective numeracy and subjective numeracy (in Step 1, all analyses controlled for the set of four covariates previously specified) using hierarchical linear regressions. Perceived stress by condition significantly predicted objective numeracy, $B = -1.03$, $SE\ B = 0.43$, $\beta = -0.29$, $p = .018$, 95% CI [−1.89, −0.18]. We do not interpret this effect further because we first sought to determine whether it replicated in Experiment 2. The interaction of condition with math anxiety was not significant ($p > .05$). When each of these moderator regression analyses were repeated with induced stress as a predictor instead of condition, no interactions reached statistical significance.

Experiment 2

Experiment 2 was conducted as a direct replication of Experiment 1. We sought to replicate the null effects obtained for the primary analyses in Experiment 1, to be adequately powered to test for interaction effects, and to have a higher proportion of male participants. All measures and methods were the same as Experiment 1, with the exception of math anxiety, which was assessed with the original item proposed by Ashcraft (2002): "On a scale of 1 to 10, with 10 being the most anxious, how math anxious are you?" from 1 (*not anxious*) to 10 (*very anxious*).

Participants

The sample size for Experiment 2 was based on an a priori power analysis that indicated that a sample size of 128 would yield 80% power to detect differences across four groups using a 2 (Stress Condition vs. Neutral Control Condition) × 2 (Male vs. Female) analysis of variance with a medium effect size of Cohen's $f = 0.25$ and $\alpha = .05$ to allow us to test gender as a moderator of effects. (In Experiment 1, examination of the unadjusted means across conditions within each gender suggested that gender might moderate the effect of condition on subjective numeracy. However, this effect was nonsignificant [$p = .166$] and involved very few male respondents.) Unfortunately, we were unable to conduct a reliable test of gender as a moderator in Experiment 2 because of unequal distribution of gender across conditions (see next section). Data were collected from 150 participants, resulting in an analytic sample size of 139 following exclusion of 11 participants (six for being suspicious of some aspect of the deception, three for not following or understanding directions, and two because of experimenter error in carrying out the deception). We stopped data collection when we reached the end of the semester to account for additional participants that would be excluded once we had the chance to more closely examine the open-ended responses used to determine suspicion. As a result, we exceeded our planned sample size of 128. A sample of 139 participants provided 90% power to detect a medium effect size of Cohen's $d = 0.50$ using one-tailed t tests (the effect we had 80% power to detect in Experiment 1) and 83% power using two-tailed t tests.

Most participants ($N = 139$) were female (67.6%) with an average age of 19.57 years ($SD = 1.46$; range = 18 to 27). Most participants (74.8%) identified as non-Hispanic White, with 11.5% Black or African American, 4.3% Asian or Asian American, 4.3% Hispanic or Latino/a, and 4.3% of mixed or other racial background. One participant did not report their race. Except for five people who were missing math anxiety data, there were no other missing data. The 11 excluded participants were higher in baseline stress, $M = 3.20$, than the 139 retained in analyses, $M = 2.28$, $t(148) = -2.24$, $p = .027$, with no differences on any other study variables (i.e., math anxiety, perceived stress, neuroticism, subjective numeracy, objective numeracy, effort on objective numeracy, induced stress, age, gender, race/ethnicity, or emotion induction condition; all $ps > .05$). The results did not change when these 11 participants were retained in analyses; the one exception is noted in the next section.

Results and Discussion

Manipulation check. Stress was higher in the stress condition than in the neutral condition (Table 1). Condition remained a significant predictor of induced stress when controlling for gender, math anxiety, baseline perceived stress, and neuroticism, $B = 0.99$, $SE\ B = 0.25$, $\beta = 0.31$, $p < .001$, 95% CI [0.50, 1.48]. There were no significant differences in baseline variables, demographic factors, or self-reported effort across conditions (Table 1).

Associations among variables. Table 2 provides correlations among study variables. Consistent with Experiment 1, objective and subjective numeracy were moderately associated, $r = .53$. Participants with higher baseline math anxiety subsequently had lower objective, $r(132) = -0.36$, $p < .001$, and subjective numeracy, $r(132) = -0.37$, $p < .001$. Those who reported greater perceived stress at baseline, $r(137) = 0.38$, $p < .001$, and greater neuroticism, $r(137) = 0.34$, $p < .001$, reported higher induced stress (Table 2).

The three postmanipulation variables did not differ as a function of race/ethnicity, objective numeracy: $t(136) = -0.54$, $p = .590$, 95% CI [−0.82, 0.47]; subjective numeracy: $t(136) = -0.39$, $p = .700$, 95% CI [−0.42, 0.28]; induced stress: $t(136) = -1.45$, $p = .148$, 95% CI [−1.06, 0.16]. However, compared to women, men were higher in objective numeracy (men: $M = 4.67$, $SD = 1.54$; women: $M = 3.76$, $SD = 1.60$), $t(137) = -3.19$, $p = .002$, 95% CI [−1.48, −0.35]; higher in subjective numeracy (men: $M = 4.09$, $SD = 0.87$; women: $M = 3.58$, $SD = 0.88$), $t(137) = -3.25$, $p = .001$, 95% CI [−0.83, −0.20]; and *lower* in induced stress (men: $M = 2.88$, $SD = 1.33$; women: $M = 3.46$, $SD = 1.66$), $t(137) = 2.05$, $p = .042$, 95% CI [0.02, 1.14]. In subsequent analyses, we controlled for math anxiety, baseline perceived stress, neuroticism, and gender as each of these variables was associated with subjective numeracy, objective numeracy, or induced stress.

Primary analyses: Predictors of numeracy. Consistent with Experiment 1, unadjusted analyses also showed no significant differences in objective or subjective numeracy across conditions (Table 1). In these unadjusted analyses, Cohen's d was 0.14 for objective numeracy and 0.31 for subjective numeracy. Similarly, in regression analyses controlling for math anxiety, baseline perceived stress, neuroticism, and gender, stress condition did not significantly predict objective or subjective numeracy, although women and those with greater baseline math anxiety had lower objective and subjective numeracy (Table 3). The pattern of significant results was the same when we replaced condition with induced stress levels (Supplemental Table 1).

We also included subjective numeracy as a predictor of objective numeracy. Subjective numeracy was a significant predictor of objective numeracy, $B = 0.78$, $SE\ B = 0.15$, $\beta = 0.44$, $p < .001$, 95% CI [0.49, 1.07]. In contrast to Experiment 1, female gender predicted lower objective numeracy, $B = 0.70$, $SE\ B = 0.28$, $\beta = 0.20$, $p = .014$, 95% CI [−0.17, 0.05], whereas math anxiety was not a significant predictor, $B = -0.06$, $SE\ B = 0.06$, $\beta = -0.09$, $p = .252$, 95% CI [−0.17, 0.05].

Moderator analyses. We next tested whether baseline math anxiety and baseline perceived stress moderated the association between condition and objective numeracy and subjective numeracy (all analyses controlled for the set of four covariates previously specified) using hierarchical linear regressions. The interactions of condition with math anxiety and baseline perceived stress were not significant (all ps $> .05$). When each of these moderator regression analyses were repeated with induced stress as a predictor, no interactions reached statistical significance (all ps $> .05$).

Equivalence Testing for Primary Analyses

Equivalence testing is recommended to statistically test for the *absence of an effect*— that is, whether observed effects are smaller than what is determined to be the smallest effect size of interest (Lakens, 2017a; Lakens, Scheel, & Isager, 2018). If the equivalence test is statistically significant, then the "hypothesis that there are effects extreme enough to be meaningful can be rejected" (Lakens, McLatchie, Isager, Scheel, & Dienes, 2020, p. 260). A complementary analysis exists in the Bayesian approach to data analysis (Harms & Lakens, 2018), and equivalence tests and Bayesian analyses often (but not always) lead to converging results (Lakens et al., 2020). We conducted post hoc equivalence tests on the differences in numeracy across conditions. This required determining the smallest effect size that would be of interest (SESOI) to researchers. The SESOI can be based on several factors, including effect sizes from prior research. However, no prior experimental research has assessed the effect of induced stress or other affect types on numeracy, which made it difficult to determine the SESOI of practical interest. Meta-analyses of conceptually similar research have shown that the effect size of stereotype threat for women in math ranges from Cohen's $d = 0.17$ to 0.36 (Spencer et al., 2016). The effect size of stress on working memory capacity ranges from Hedges $g = -0.32$ to -0.44 (Moran, 2016). Thus, the effect of stress on numeracy, if present, might correspond to anywhere from a small to medium-to-small effect size. Therefore, we set the SESOI to $d = -0.35$ (an effect that was midway between a standard small [$d = 0.2$] and medium [$d = 0.5$] effect size) for the lower equivalence bound and $d = 0.35$ for the higher equivalence bound. However, because the studies were powered for a medium effect size, we also conducted equivalence testing with an SESOI of $d = 0.50$. Because the studies were only powered for a medium effect size, we also conducted equivalence tests with a combined sample across both experiments. A sample of 238 participants has 77% power to detect a medium-to-small effect size of Cohen's $d = 0.35$ using two-tailed t tests.

Table 4 presents the statistical output from multiple sets of equivalence tests. We first conducted equivalence tests for Experiments 1 and 2 considered separately. Using a medium-to-small effect size ($d = 0.35$), these equivalence tests for both objective and subjective numeracy were nonsignificant, indicating that the observed effects were statistically *not* equivalent to zero. This means that medium-to-small effects cannot be ruled out for either outcome. For a medium effect size ($d = 0.50$), the equivalence test for subjective numeracy in Experiment 1 was similarly nonsignificant. However, using a medium effect size, the equivalence tests for objective numeracy in both experiments and for subjective numeracy in Experiment 2 were statistically significant. This means the observed effects *were* statistically equivalent to zero, which provides support for the null hypothesis and suggests that medium-sized effects of stress are unlikely to exist.

As shown in Table 4, pooling the sample across both experiments yielded a nonsignificant equivalence test for only one of the four analyses: a medium-to-small effect for subjective numeracy. In sum across the series of equivalence tests for each experiment separately and combined, any effects of stress on objective numeracy are likely smaller than a medium-to-small-sized effect. For subjective numeracy, a medium-sized effect can be ruled out. However, it remains possible that stress has a medium-to-small or smaller-sized effect on subjective numeracy.

Comparison Across Experiments and Meta-Analysis

We took two additional steps to have greater confidence in the results. First, we summarized which effects replicated across Experiments 1 and 2 (Supplemental Table 1). Most effects replicated across experiments. Of those that did not, most involved gender, which is unsurprising given that there were so few men in Experiment 1, and this was one reason we conducted Experiment 2. Second, we conducted a continuously cumulating meta-analysis (CCMA; Braver et al., 2014) for the primary analyses of whether objective and subjective numeracy differed across conditions in bivariate analyses. When considering both experiments, neither effect reached statistical significance (objective numeracy: pooled effect = −0.12, 95% CI [−0.37, 0.14], $p = .368$; subjective numeracy: pooled effect = −0.24, 95% CI [−0.50, 0.02], $p = .065$). Further, the effect sizes for the differences in objective and subjective numeracy across conditions were similar for the two experiments, as indicated by nonsignificant Q statistics (objective: $p = .862$; subjective: $p = .630$) and I^2 of 0 for both effects (Braver et al., 2014).

In sum, we compared results across two experiments, conducting equivalence tests, and conducting a CCMA. Based on all of these data, we can be fairly certain that the stress inductions implemented across both experiments did not affect objective numeracy (although an effect smaller than medium-to-small could exist). The evidence was less conclusive that the stress inductions did not have an effect on subjective numeracy.

Discussion

People must make decisions with numbers when in different affective states. These affective states could be unrelated to the decision (e.g., feeling stressed when getting stuck in traffic on the way to a doctor's appointment) or could directly involve anxiety about using numbers to make decisions (e.g., disliking math or feeling apprehensive about trying to make a mathematically accurate medical decision). We examined the associations among objective numeracy and subjective perceptions of one's numeracy with (a) induced stress caused by anticipating giving a speech (i.e., stress unrelated to math), (b) math anxiety (i.e., stress related to math), and (c) perceived stress in the last month (i.e., a measure of chronic, preexisting stress). Contrary to hypotheses, participants who underwent a laboratory-based stress induction had comparable objective and subjective numeracy following the stress induction to participants who were in a neutral condition. This lack of an effect of stress on numeracy suggests that numeracy measures may be robust to some types of contextual changes. This is consistent with data showing that subjective numeracy scores were similar when the scale was completed before and after participants solved difficult math problems (Galesic & Garcia-Retamero, 2010). In the present study, participants' degree of perceived stress in the last month was also not associated with numeracy. However, math anxiety *was* consistently associated with objective math performance and with subjective perceptions of math ability.

Is Numeracy Impacted by In-the-Moment Fluctuations in Affective States?

We cannot conclude that numeracy is resistant to moment-to-moment affective influences without knowing whether it is affected by other negative emotional states (e.g., fear, sadness, happiness, etc.). For example, numeracy scores in one study were lower when the questions were framed about negative health consequences and risk versus a neutral context (Levy, Ubel, Dillard, Weir, & Fagerlin, 2014). This suggests that health versus nonhealth contextual factors can influence numeracy. Recent research also indicates that numeracy can be improved over a longer period of time (Peters et al., 2017). Students in a psychology statistics course who underwent a self-affirmation intervention—writing about why a personal value was important—showed improved numeracy over 9 weeks (Peters et al., 2017). It is possible that this improvement may only occur in the context of math exposure: the statistics course likely involved content related to both objective and subjective numeracy and, thus, does not confirm whether numeracy is malleable in the moment or can be improved over a period of days. Further, based on the equivalence tests we conducted, we cannot conclusively rule out the presence of medium-to-small effects of stress on subjective numeracy or small effects on objective numeracy.

From a developmental perspective, the ability to solve problems and think about mathematical relationships develops over the life span (Common Core Standards Writing Team, 2013) and can be improved through interventions involving feedback (Opfer & Siegler, 2007; Opfer & Thompson, 2008). Specifically, older chil-

Table 4
Statistical Information for Equivalence Tests

Variable	Means	Standard deviations	Sample sizes	Statistics, medium effect size (d = .50)	Statistics, medium-to-small effect size (d = .35)
Experiment 1					
Objective numeracy	M1 = 3.52; M2 = 3.75	SD1 = 1.56; SD2 = 1.64	S1 = 48; S2 = 51	$t(97.0) = 1.77, p = .040$	$t(97.0) = 1.03, p = .154$
Subjective numeracy	M1 = 3.57; M2 = 3.85	SD1 = .89; SD2 = .89	S1 = 48; S2 = 51	$t(96.6) = 0.92, p = .179$	$t(96.6) = 0.18, p = .430$
Experiment 2					
Objective numeracy	M1 = 3.97; M2 = 4.13	SD1 = 1.64; SD2 = 1.63	S1 = 69; S2 = 70	$t(136.9) = 2.37, p = .010$	$t(136.9) = 1.49, p = .070$
Subjective numeracy	M1 = 3.66; M2 = 3.83	SD1 = .98; SD2 = .83	S1 = 69; S2 = 70	$t(132.8) = 1.84, p = .034$	$t(132.8) = 0.96, p = .170$
Pooled					
Objective numeracy	M1 = 3.79; M2 = 3.97	SD1 = 1.61; SD2 = 1.64	S1 = 117; S2 = 121	$t(235.9) = 3.00, p = .002$	$t(235.9) = 1.85, p = .033$
Subjective numeracy	M1 = 3.62; M2 = 3.84	SD1 = .94; SD2 = .85	S1 = 117; S2 = 121	$t(231.8) = 1.96, p = .026$	$t(231.8) = 0.81, p = .211$

Note. M1, SD1, and S1 refer to stress condition. M2, SD2, and S2 refer to neutral control condition.

dren and adults reason more accurately about fractions than younger children (Fazio, DeWolf, & Siegler, 2016; Sidney, Thalluri, et al., 2019; Siegler, Thompson, & Schneider, 2011). Thus, from a developmental perspective, objective numeracy should be malleable because it relies on math ability that develops over the life span. Adults and fifth- and sixth-grade children have less positive attitudes about fractions and percentages than whole numbers (Sidney, Thompson, et al., 2019). It is an open question whether children have more positive attitudes about fractions when they first begin learning about them in third grade. Thus, it is possible that subjective numeracy is somewhat malleable, but elementary students already harbor less positive attitudes about difficult rational number concepts.

Consistent with prior research, we found that math anxiety was associated with lower objective and subjective numeracy (Peters et al., 2017; Rolison et al., 2016). Why might math anxiety be related to objective and subjective numeracy? Although it is possible that lower numeracy causes greater math anxiety, it is more likely that greater math anxiety causes lower numeracy (Hembree, 1990). Specifically, a history of math anxiety may cause people to disengage from opportunities to learn math concepts (Hembree, 1990). People with higher math anxiety are less accurate on rational number tasks (Sidney, Thalluri, et al., 2019), and people dislike rational numbers more than other types of numbers (Sidney, Thompson, et al., 2019). Thus, people with high math anxiety may avoid rational numbers, which they dislike and perform poorly on. This could account for the inverse relation between math anxiety and numeracy measures that involve rational numbers. Additionally, math anxiety impairs performance in the moment, regardless of actual underlying competency (Ashcraft, Kirk, & Hopko, 1998). Math anxiety likely affects mental calculation by depleting available working memory resources (Ashcraft & Krause, 2007). Supporting the effect of math anxiety on math performance, effective treatments for math anxiety can improve highly anxious students' math achievement scores to the level of students who are not anxious (Hembree, 1990). Nevertheless, additional research is needed to tease out the causal relationships among these factors.

General and Domain-Specific Affective Influences

Methodologically, it is difficult to distinguish between stress that is unrelated to the math at hand (i.e., stress about giving a speech) versus apprehension related to the math at hand (i.e., preexisting math anxiety). In real-life decisions involving numbers, it is probably impossible to disentangle general stress from math anxiety because objective and subjective numeracy measures involve numbers, and completing complex math tasks activates math anxiety (Ashcraft, 2002). Surprisingly, in the present study, math anxiety did not compound the effects of general stress induced from preparing a speech. Put differently, the association of math anxiety and numeracy did not depend on whether stress was induced. These data tentatively suggest that anxiety related to numbers themselves may harm numeracy more than generalized stress. Future research could test whether inducing math anxiety influences numeracy. In fact, a common stress induction involves a difficult math task in which participants serially subtract 13 from 1,022 in front of an audience (Kirschbaum, Pirke, & Hellhammer, 1993).

Laboratory stress inductions are commonly used to ethically determine causal effects of stress (Dickerson & Kemeny, 2004; Steptoe, Hamer, & Chida, 2007). These acute stress tasks are used to mimic precursors of chronic stress as both acute and chronic stress have long-term effects on the body (McEwen, 1998). Although the stress induction we used reliably increased self-reported stress with a large effect size, one common stress induction typically lasts longer and involves actually giving a speech and completing math tasks (Kirschbaum et al., 1993). Perhaps a more involved stress induction would have affected numeracy. Relatedly, stress experienced in the "real world"—for example, during a doctor's visit—could exceed that experienced during our laboratory induction. However, preexisting stress as measured by the Perceived Stress Scale was *not* associated with either objective or subjective numeracy, although this may be distinct from experiencing high levels of "real world" stress in the current moment.

Limitations and Future Directions

The present study provided no statistical evidence that induced stress predicted numeracy. This was true when analyses were and were not adjusted for related factors such as gender, math anxiety, baseline perceived stress, and neuroticism and when measured as participants' individual levels of induced stress on the manipulation check. However, there are several limitations. We did not assess basic math abilities such as number sense (Dehaene, 2011), magnitude understanding (Siegler, 2016), standardized math achievement, or number of math courses taken. More specifically, we did not measure rational number problem-solving performance, which is a main component of objective and subjective numeracy measures. Because we do not know whether rational number ability was equally distributed across conditions, we cannot rule out that greater math anxiety was caused by lower mathematical ability. Because we were testing an applied question (*Does* stress influence numeracy?) rather than testing for a mechanism (*Why* does stress influence numeracy?), we also did not measure any potential proximal mechanisms (e.g., working memory load or inability to concentrate) through which stress might affect numeracy.

The current findings should be replicated with other measures of numeracy. One such measure is the well-validated Berlin Numeracy Scale (Cokely et al., 2012). A potential limitation of the Rasch-Based Numeracy Test used here is that it measures cognitive impulsivity as well as numeracy, which may be conceptually distinct (Ghazal, Cokely, & Garcia-Retamero, 2014).

Several effects involving gender were significant in Experiment 2 but not Experiment 1 (Supplemental Table 1). Only 11% of participants in Experiment 1 were male, making gender effects difficult to observe. As a result, we have less confidence in gender effects than other effects identified here because they were obtained in only one of the two experiments. In Experiment 2, women reported lower objective and subjective numeracy than men, consistent with prior research in which women exhibited lower numeracy (Galesic & Garcia-Retamero, 2010; Peters & Bjalkebring, 2015). Unfortunately, despite random assignment to condition, there were somewhat more men in the control (M = 40%) than stress condition (M = 25%) in Experiment 2. However, given men's higher numeracy, their greater representation in the control condition should have *increased* the likelihood of identifying significant differences in numeracy across conditions. Although women reported greater induced stress after preparing a speech, it is unlikely that greater induced stress accounted for lower numeracy because induced stress was not significantly associated with objective *or* subjective numeracy.

Another limitation is that the individual experiments were powered to detect medium but not smaller effect sizes. Given the lack of previous research specifically examining the effect of stress on numeracy, a small effect size is possible. Equivalence tests suggested that even after pooling samples across the two experiments, the observed effect for subjective numeracy was not statistically equivalent to zero even for a medium-to-small effect size.

Given the practical constraint of running the study in person given the deception involved, it would be difficult to recruit a sample large enough to detect a small effect size of Cohen's d = 0.2 using two-tailed t tests with 80% power—this would require 788 respondents. To our knowledge, there is no effective way to induce stress in an online context; an online induction would make it more feasible to recruit a larger sample. The current experiments, which we consider a first step in testing the effect of affective influences on numeracy, provide useful values for determining what effect size to power for in future research. We hope the preliminary evidence obtained here will spur replication efforts with samples powered to observe small and medium-to-small effects. Resources exist to help researchers make more informed decisions with respect to power and sample sizes (Giner-Sorolla et al., 2019). Future research will also benefit from preregistering hypotheses, data analysis plans, methodological choices such as sample size, and determining the smallest effect size of interest a priori.

If we accept the null results, one explanation as to why the stress induction did not influence objective numeracy scores is that because of the lower scores overall, there was limited potential for the stress induction to cause further decreases in numeracy. However, the current sample did answer about half of the problems correctly, and their low scores likely illustrate the challenging nature of the objective numeracy problems. Participants in the present study performed quite a bit lower on the objective numeracy measure than another sample drawn from a more selective university (Peters, Västfjäll, et al., 2006). This is consistent with data indicating that rational number understanding differs across more- and less-selective university settings (Fazio, Kennedy, & Siegler, 2016). Thus, the numeracy scores of the current sample may be higher than scores from a general population as participants were recruited from a higher education setting but lower than students from more selective universities.

Another possible explanation for the null effects of stress on numeracy is that the induced affect may have dissipated by the time we measured numeracy. We were surprised to realize (following the suggestion of an anonymous reviewer) that the mean duration of cardiovascular reactivity following a stress induction very similar to one used here was only 29.6 s (SD = 19.6; Tugade & Fredrickson, 2004). However, Yip and Côté (2013), from whom we adapted our stress induction, conducted two studies in which they found a negative effect of induced anxiety on risk-taking following completion of a three-item manipulation check. In the present study, participants' stress levels should have remained elevated while completing the numeracy measures because they were still anticipating giving a speech; we excluded participants who expressed suspicion that they would not give the speech. Nevertheless, induced stress could have dissipated for some participants by the time they completed the numeracy measures.

Practical Relevance for Health Care and Education

Numeracy is a robust predictor of health judgments, decisions, and outcomes (Lipkus & Peters, 2009; Nelson et al., 2008; Peters, 2012; Reyna & Brainerd, 2007; Reyna et al., 2009). For example, greater numeracy predicts more accurate appraisal of the benefits of screening procedures (Schwartz et al., 1997), more accurate judgments of risk (Garcia-Retamero & Galesic, 2009), and less delay in medical care-seeking (Petrova et al., 2017). Further, it has been stated that "Knowing an individual's numeracy may be an important first step in conveying numeric information about genetics and genomics" (Lea, Kaphingst, Bowen, Lipkus, & Hadley, 2011, p. 284), given that numeracy can influence the best way to present risk information (Peters, 2012). Although we do not report data on decision-making outcomes here, our findings have important practical implications given that numeracy is a well-established predictor of medical and financial outcomes. In the current study, we conceptualized affective influences, such as stress and math anxiety, as factors that could indirectly affect health outcomes through their influence on numeracy, rather than as direct predictors of health outcomes. We examined numeracy specifically because of its practical implications.

Our finding that adults' numeracy was similar regardless of their current stress levels suggests an important measurement implication: numeracy measures should be reliable predictors of decision-making outcomes, regardless of whether participants are experiencing non-math-related stress while completing the measures. From a research perspective, this is important because it suggests numeracy is a valid measure that is not impacted by moment-to-moment fluctuations in affect. Future research can determine whether other tasks involving math performance, perhaps that have been less robustly validated, are similarly resistant to affective influences.

With respect to health care settings, understanding how best to present numeric health information is critical. If numeracy is not easily influenced by moment-to-moment changes in affect as suggested here, health care providers can be confident that their patients will be equally able to interpret numeric information regardless of their current stress levels. On the other hand, given that math anxiety—a characteristic that people bring with them to health care decisions—was a consistent predictor of objective and subjective numeracy, it could be important to identify patients high in math anxiety. Assessing patients' math anxiety should be straightforward in an applied health care setting since it can be reliably assessed with a single item (Ashcraft, 2002). Although correlational, the association between math anxiety and numeracy suggests that interventions to help adults manage their math anxiety could improve their numeracy. Expressive writing has been used to reduce intrusive, math-anxious thoughts (Park, Ramirez, & Beilock, 2014, but see Camerer et al., 2018 for a replication failure). Combining behavioral (i.e., systematic desensitization) and cognitive (i.e., cognitive restructuring) therapy appears to reduce overall math anxiety and subsequently increase math test scores (Hembree, 1990). A developmental approach in which math anxiety is targeted early in the life span, especially given children's early attitudes about rational numbers, could have downstream implications for health decisions via the mechanism of improved numeracy.

In the current experiments, we identified factors that were and were not associated with numeracy. Understanding these factors, and developing and testing interventions to improve numeracy, has implications not only for health decisions but also financial and career-related decisions. Multiple educational interventions exist to improve rational number understanding (Fazio et al., 2016; Fuchs et al., 2013; Hamdan & Gunderson, 2017; Moss & Case, 1999; Opfer & DeVries, 2008; Rittle-Johnson, Siegler, & Alibali, 2001). These interventions, developed primarily by math cognition researchers, may also improve performance on objective and subjective numeracy measures given that these numeracy measures are comprised of preferences for and computations with rational numbers. That is, if rational number understanding can be improved in one educational context, then these improvements should transfer to other applied contexts. It is important to link research across health decision-making and cognition to ensure that research moves forward efficiently and with fidelity, without duplicating efforts in scientific silos.

With the advent of precision medicine and the emphasis on individual variability in prevention and treatment (Ashley, 2015; Collins & Varmus, 2015), people will increasingly receive individualized disease risk information. Within this context of widespread availability of information and the rise of a consumer-driven approach to health care, individuals are encouraged to take more responsibility for their medical decisions and well-being (Reyna et al., 2009). Thus, understanding whether and how emotions impact understanding and interpretation of rational numbers may have critical health implications.

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