

The Role of Expressive Writing in Math Anxiety

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Math anxiety is a negative affective reaction to situations involving math. Previous work demonstrates that math anxiety can negatively impact math problem solving by creating performance-related worries that disrupt the working memory needed for the task at hand. By leveraging knowledge about the mechanism underlying the math anxiety–performance relationship, we tested the effectiveness of a short expressive writing intervention that has been shown to reduce intrusive thoughts and improve working memory availability. Students ($N = 80$) varying in math anxiety were asked to sit quietly (control group) prior to completing difficulty-matched math and word problems or to write about their thoughts and feelings regarding the exam they were about to take (expressive writing group). For the control group, high math-anxious individuals (HMAs) performed significantly worse on the math problems than low math-anxious students (LMAs). In the expressive writing group, however, this difference in math performance across HMAs and LMAs was significantly reduced. Among HMAs, the use of words related to anxiety, cause, and insight in their writing was positively related to math performance. Expressive writing boosts the performance of anxious students in math-testing situations.

Keywords: anxiety, expressive writing, performance, intervention, working memory

Math anxiety is defined as feelings of tension, apprehension, and fear of situations involving mathematics (Ashcraft & Moore, 2009) and is associated with poor math performance. Individuals with a high degree of math anxiety receive lower grades in math courses from elementary school through college relative to their lower math-anxious counterparts (Betz, 1978; Ma, 1999) and tend to avoid courses and careers that involve mathematics (Hembree, 1990). Math anxiety is also, unfortunately, prevalent in our society; as many as 25% of 4-year university students and 80% of community college students suffer from a high degree of math anxiety (Yeager, 2012).

Math anxiety is not only negatively related to math performance in school, but this relationship can be also seen in the workplace and beyond. For instance, math anxiety and an aversion to math situations are associated with poorer drug calculation among nurses (McMullan, Jones, & Lea, 2012), reduced teaching self-efficacy among elementary teachers (Swars, Daane, & Giesen, 2006), and impaired financial planning (McKenna & Nickols,

1988). Given the negative consequences associated with math anxiety, identifying ways to disarm its deleterious effects is important. In the current study, we leveraged knowledge about the cognitive mechanisms by which math anxiety relates to math performance to test an intervention designed to boost math-anxious students' performance on math tests.

Why Do Math-Anxious Students Tend to Perform Poorly in Math?

Although previous research has identified an association between math anxiety and poor math performance, math anxiety is not just a proxy for poor math skills. For instance, even though high math-anxious individuals (HMAs) underperform relative to low math-anxious individuals (LMAs) on basic numerical tasks (e.g., counting objects and numerical comparison; Maloney, Ansari, & Fugelsang, 2011; Maloney, Risko, Ansari, & Fugelsang, 2010), poor math skills do not fully account for the math anxiety–performance relationship. Rather, worries and intrusive thoughts about math situations are thought to rob HMAs of an important cognitive resource, *working memory*, which is often necessary to hold intermediate steps in mind and compute solutions to difficult problems on math tests. Working memory is a limited cognitive resource involved in consciously holding and manipulating task-relevant information (Engle, 2002; Just & Carpenter, 1992). When working memory is compromised, an individual's ability to perform at a high level can suffer.

Evidence for the aforementioned worry account of math anxiety primarily comes from work by Ashcraft and his colleagues (Ashcraft & Faust, 1994; Ashcraft & Kirk, 2001; Faust, Ashcraft, & Fleck, 1996), who have shown that HMAs' math deficits are most

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apparent in complex math problems that rely heavily on working memory (e.g., two-column addition problems that involve a carry operation such as $27 + 18$). In contrast, HMAs perform similarly to LMAs in basic math problems that do not require the same degree of cognitive control (e.g., single digit addition problems such as $4 + 3$; Ashcraft & Faust, 1994; Ashcraft & Kirk, 2001; Faust, Ashcraft, & Fleck, 1996). Ashcraft and colleagues argue that one of the primary ways in which math anxiety hurts HMAs' performance is by creating a dual-task situation in which students must manage both intrusive thoughts and the component processes (e.g., the manipulation of large numbers involving a carry operation) necessary for solving math problems.

In the current work, we explored an intervention designed to combat math anxiety's negative impact on math performance by reducing performance worries: *expressive writing*. Prior attempts at reducing the impact of math anxiety on math performance have primarily focused on improving the math skills of HMAs (Bander, Russell, & Zamostny, 1982; Hendel & Davis, 1978; Simon & Schifter, 1993). Surprisingly, less attention has been focused on addressing the worry component of math anxiety. If worries in math situations compromise important working-memory resources that could otherwise be devoted to the task at hand, then it follows that interventions that reduce the impact of these worries should serve to boost math performance.

Expressive Writing as an Intervention for Math Anxiety

Expressive writing is a simple, clinical technique that encourages individuals to write freely about their thoughts and feelings regarding an important stressor they are facing (Pennebaker & Beall, 1986). Previous work indicates that writing about a stressful or emotional event for 15–20 minutes can—after several bouts of writing across time—provide both physical and psychological benefits for clinical (e.g., depressed patients; Gortner, Rude, & Pennebaker, 2006) as well as nonclinical populations (e.g., first year college students; Klein & Boals, 2001). For instance, expressive writing has been shown to reduce negative thoughts and ruminations in anxious and depressed populations (Donnelly & Murray, 1991; Graf, Gaudiano, & Geller, 2008).

Expressive writing can also increase the availability of working-memory resources (Klein & Boals, 2001; Yogo & Fujihara, 2008). After three 20-min writing sessions, college students who wrote about their thoughts and feelings regarding college life showed significant gains in working-memory availability when compared with those who wrote about a trivial topic (Klein & Boals, 2001). Furthermore, expressive writing can help reduce the impact of stressful exam situations on performance. Recently, Ramirez and Beilock (2011) demonstrated that individuals who were instructed to write for 10 min about their feelings and thoughts about an immediately upcoming exam (taken in a contrived laboratory setting) performed significantly better than those who did not write or wrote about an unrelated topic. Furthermore, it was shown that writing about negative thoughts and ruminations helps explain the benefits of expressive writing on high-stakes test performance. The benefits of expressive writing even extend to the classroom, where students must contend with acute stress derived from final examinations (Ramirez & Beilock, 2011), as well as standardized tests such as the Medical College Admission Test (MCAT) or Law

School Admission Test (LSAT; Frattaroli, Thomas, & Lyubomirsky, 2011).

Using the aforementioned work as a jumping board, we explored whether expressive writing could reduce the negative impact of math anxiety on math performance. Although expressive writing has been shown to be an effective intervention for reducing negative affect and rumination in a high-stakes testing situation (Frattaroli et al., 2011; Ramirez & Beilock, 2011), it remains an open question as to whether expressive writing can improve the math performance of individuals who suffer from an acute and long-held fear of mathematics (i.e., HMAs). Given that research suggests that children develop math anxiety early in schooling (Ramirez, Gunderson, Levine, & Beilock, 2013; Vukovic, Kieffer, Bailey, & Harari, 2013; Wigfield & Meece, 1988; Young, Wu, & Menon, 2012) and that children's math anxiety increases across schooling (Gottfried et al., 2012; Hembree, 1990), it is easy to imagine how a single bout of expressive writing might not be powerful enough to off-set the worries of a stressor with a long history in a student's academic development. Furthermore, simply writing about one's worries may not be powerful enough to mitigate the sociopersonal factors that are associated with math anxiety, such as lower self-efficacy (McMullan et al., 2012) and lack of enthusiasm for math (Wood, 1988). On the other hand, if performance worries are a primary factor influencing math performance among HMAs, then one bout of expressive writing may be sufficient to improve math performance.

Present Study

In the current study, we evaluated the effect of expressive writing on the math-anxiety–math-performance relationship. To do this, we randomly assigned LMAs and HMAs, who were pre-screened and specifically selected because of their lower or higher levels of reported math anxiety, to either write about their worries (expressive writing group) or to sit quietly (control group) before an exam. Previous work has shown that the performance of this type of control group does not differ from that of a control group assigned to write about an irrelevant topic (Klein & Boals, 2001; Ramirez & Beilock, 2011). Because it is not the act of writing in itself that is beneficial (Klein & Boals, 2001; Ramirez & Beilock, 2011), but expressive writing in particular that can potentially confer performance benefits, we chose to have our control group parallel what often happens in real exam situations. This specific control condition was chosen to mimic as closely as possible the “business-as-usual” waiting that students often do right before an exam. After 7 min of either writing or sitting quietly, all participants took an exam that consisted of both math and word problems, varying in the demands they placed on working memory.

We predicted that HMAs would perform significantly worse than LMAs on math problems when they sat quietly before completing the math task. We expected math-performance deficits to be particularly apparent when participants solved problems with high working-memory demands. However, after a single session of expressive writing, we predicted that HMAs would perform at a comparable level to LMAs. Last, we were interested in demonstrating that HMAs show a more pronounced performance decrement than LMAs in math as compared with a nonmath-related task. Such a result would mirror previous findings in the literature, showing a more negative relation between math anxiety and math-

problem performance than between math anxiety and academic performance in general (e.g., Ashcraft, 2002; Lyons & Beilock, 2012). To test for this, we included a set of word problems that were matched in difficulty with the math problems (Lyons & Beilock, 2012).

Method

Online Prescreening

Students from a Midwestern university were prescreened for math anxiety using a common 25-item self-report measure (Short Math Anxiety Rating Scale; SMARS; Alexander & Martray, 1989) that asks individuals to rate how anxious they would feel during various situations that involve math (e.g., “Receiving a math textbook;” 0, *not at all*; 1, *a little*; 2, *a fair amount*; 3, *much*; 4, *very much*). The possible range of scores on the SMARS is from 0 to 100. Based on previously published work with the same population (Lyons & Beilock, 2012), individuals who scored below 20 (meaning they answered mostly 0s and 1s on the scale) were classified as LMAs and those who scored over 40 (2s or above) were classified as HMAs. This was roughly equal to the lower and upper quartiles of our prescreening sample. Math-anxiety scores for HMAs ($M = 54.14$, $SD = 11.08$) and LMAs ($M = 14.53$, $SD = 4.12$) were significantly different from each other, $t(78) = 20.31$, $p < .001$.

We also collected measures of students’ test anxiety during prescreening using a 27-item self-report questionnaire (Cognitive Test Anxiety Scale; Cassady & Johnson, 2002). Given that math anxiety is often comorbid with general test anxiety (Betz, 1978; Richardson & Woolfolk, 1980), it is possible that the math-anxiety–math performance relationship is exaggerated by test anxiety (Devine, Fawcett, Szucs, & Dowker, 2012). Therefore, we collected test-anxiety scores to use as a covariate in our analyses to ensure that our findings could not be accounted for by a general anxiety about taking tests.

Items for the test-anxiety questionnaire asked individuals to rate how anxious they would feel during general testing situations (e.g., “I tend to freeze up on things like intelligence tests and final exams;” 1, *not at all typical of me*; 2, *only somewhat typical of me*; 3, *quite typical of me*; 4, *very typical of me*). Using a sum of all the items, the possible range of sum scores was from 27 to 108. In line with past work (Betz, 1978), we found that HMAs ($M = 74.34$, $SD = 13.00$) reported higher test anxiety than LMAs, $M = 52.19$, $SD = 11.20$; $t(78) = 8.06$, $p < .001$. Similar to previous reports in the literature (Devine et al., 2012; Hembree, 1990), there was an association between math anxiety scores and test anxiety-scores, $r(78) = .67$, $p < .001$.

Participants

Eighty participants were invited to participate in the main study based on the online prescreening. Forty-four participants were identified as HMAs and 36 were identified as LMAs. Four additional subjects were tested but excluded because they did not follow instructions (were reading a book during the writing period, $n = 2$) or performed at chance level on one or more of the problem types in the main exam ($n = 2$).

Exam Tasks

A set of math and word tasks adopted from Lyons and Beilock (2012) were used as stimuli. The *math task* presented participants with simple arithmetic problems in the form of $(a \times b) - c = d$, where $a \neq b$, $c > 0$, $d > 0$. Participants were asked to decide whether the problems were solved correctly or not by pressing the “C” key for the correctly solved problems and the “M” key for the incorrectly solved problems. The math task consisted of 30 math problems with high working-memory demands (high demands) and 30 math problems with low working-memory demands (low demands). High-demand math problems were operationalized as those in which $5 \leq a \leq 9$, $5 \leq b \leq 9$ ($a \times b \geq 30$), and $15 \leq c \leq 19$. In addition, subtracting c from $(a \times b)$ always required a borrow operation, for example, $(6 \times 9) - 15 = 39$. Low-demand math problems were operationalized as $1 \leq a \leq 9$, $1 \leq b \leq 9$ ($a \times b \leq 9$), and $1 \leq c \leq 8$. In addition, subtracting c never required a borrow operation, for example, $(3 \times 2) - 4 = 2$. Problems with high demands involved higher numbers and borrowing operations, whereas problems with low demands involved lower numbers and no borrowing operations.

The *word task* presented participants with letter strings. Participants were asked to verify whether the letter string spelled an English word when reversed (e.g., *tnemirepxe*). For half of the words, two adjacent letters were switched and the whole reversed letter string was a nonword (e.g., *debimlc*). Participants were asked to make a decision by pressing the “C” key for an actual English word and the “M” key for a nonword. The word task consisted of 30 word problems with low demands and 30 word problems with high demands. Low-demand word problems had four letters; high-demand problems had seven letters. This task has very similar properties to the math task. Specifically, both tasks are forced-choice problems, and both are comparable in terms of difficulty as measured by overall reaction time (RT) and error rates (Lyons & Beilock, 2012).

The main exam consisted of 60 math problems and 60 word problems (half high-demand, half low-demand). The exam was divided into a series of consecutive math and word problem blocks, each containing 12 problems (half high-demand, half low-demand). The order of the math and word blocks was alternated and problems were randomly presented within blocks. Between blocks, participants received a 500-ms cue indicating the type of problems that were coming up, either “word problems” or “math problems.” The first block was counterbalanced, that is, some participants received a word block first and others received a math block first.

Procedure

Participants began by completing an initial practice exam involving six high-demand math and six high-demand word problems. This practice exam was designed to orient participants to the problems and to elicit anxiety in HMAs. Following the completion of the practice problems, participants were randomly assigned within math anxiety group to either the expressive writing or the control group. Participants assigned to the expressive writing group (22 HMAs, 18 LMAs) were asked to write about their deepest thoughts and feelings about the upcoming math exam (which they did on the computer). Specifically, participants in the expressive writing condition read

Please take the next 7 minutes to write as openly as possible about your thoughts and feelings regarding the math problems you are about to perform on the Excel spread sheet. In your writing, I want you to really let yourself go and explore your emotions and thoughts as you are getting ready to start the second set of math problems. You might relate your current thoughts to the way you have felt during other similar situations at school or in other situations in your life. Please try to be as open as possible as you write about your thoughts at this time. Remember, there will be no identifying information on your essay. None of the experimenters, including me, can link your writing to you. Press the enter key at the end of every sentence to start a new sentence in the next row. When I knock on the door please stop writing and cover up the text so that I can't see what you wrote.

After 7 min of writing, the experimenter entered the room and instructed participants to put away their writing by giving the document a pseudo file name and saving it in a folder on the hard drive. In contrast, those assigned to the control group (22 HMAs, 18 LMAs) were asked to wait quietly for an experimenter to bring some additional materials to the experiment. Both groups were given 7 min to write or sit. Immediately after the time was up, all participants began the main exam consisting of 60 math problems and 60 word problems.

Results

We begin by looking at RT and error rates, separately, for the math and word problems. We then combine these two performance measures into a composite RT and error-rate measure as a means to capture test performance as a whole, because test performance often has both accuracy and time components (Bruyer & Brysbaert, 2011; Salthouse & Hedden, 2002). We also included test-anxiety score as a covariate in our main analysis to ensure that math anxiety specifically, not general apprehension for evaluative situations, was responsible for our results. While our results remained largely the same whether we used test anxiety as a covariate or not, we have highlighted the specific analysis that yielded differences (i.e., changed in significance level above or below the standard $p < .05$) when we did not covariate test anxiety out.

Reaction Time (RT)

Analysis of the RT data only included trials solved correctly. We removed RTs that were 3 *SDs* above and below each participant's mean within the cell crossing of task domains (math, word) and problem-demand levels (low, high). This procedure removed 1.2% of the total correct trials. Table 1(left) presents RT data.

Math RT. Among participants in the control condition, HMAs ($M = 6,793.70$, $SD = 3,768.03$) spent significantly more time on high-demand problems than their LMA counterparts ($M = 4,218.53$, $SD = 1,285.96$), $F(1, 37) = 4.67$, $p < .05$. However, among participants assigned to the expressive writing condition, we found that HMAs' RT ($M = 5,296.01$, $SD = 2,131.52$) did not significantly differ from LMAs' RT ($M = 4,949.82$, $SD = 2,085.46$), $F(1, 37) = 1.15$, $p > .20$. A significant Math Anxiety (LMAs, HMAs) \times Writing Group (expressive writing, control) interaction on high-demand math problems confirmed that whether HMAs solved high-demand math problems more slowly than LMAs depended on whether they took part in our writing intervention, $F(1, 75) = 4.56$, $p < .05$. Note: when test anxiety was not controlled, $F(1, 76) = 3.77$, $p = .056$.

A nonsignificant Math Anxiety \times Writing Group interaction on low-demand math problems indicated that the effects of math anxiety did not vary as a function of writing condition, $F(1, 75) = 2.38$, $p > .10$. However, it should be noted that, in the control condition, there was a performance difference between HMAs and LMAs, $F(1, 37) = 4.27$, $p < .05$. In the expressive writing condition, the gap was not significant, $F(1, 37) = 2.17$, $p > .10$.

Word RT. A marginally significant Math Anxiety \times Writing Group interaction was found for high-demand word problems, $F(1, 75) = 3.66$, $p = .06$, but not low-demand word problems, $F(1, 75) = .29$, $p > .50$. However, there were no significant RT differences between HMAs and LMAs assigned to either the control or expressive writing conditions for either high-demand or low-demand word problems, all $ps > .10$. Note: when test anxiety did not serve as a covariate, we found that HMAs and LMAs

Table 1
Mean Error Rates and Mean Reaction Time (RT) Across Groups

Group	RTs (ms)		Error rates	
	Control	Expressive writing	Control	Expressive writing
Math				
Low-demand problems				
LMAs	1824.69 (429.22)	1896.20 (524.62)	.05 (.05)	.02 (.03)
HMAs	2313.90 (514.49)	2064.72 (592.13)	.03 (.03)	.02 (.03)
High-demand problems				
LMAs	4218.53 (1285.96)	4949.82 (2085.46)	.13 (.06)	.13 (.12)
HMAs	6793.70 (3768.03)	5296.01 (2131.52)	.21 (.13)	.16 (.11)
Word				
Low-demand problems				
LMAs	1657.64 (671.42)	1697.21 (655.94)	.09 (.07)	.08 (.05)
HMAs	1826.79 (487.58)	1741.25 (488.46)	.12 (.08)	.11 (.09)
High-demand problems				
LMAs	2869.38 (867.49)	3289.91 (1271.93)	.16 (.10)	.11 (.07)
HMAs	3761.11 (1512.84)	3216.67 (858.93)	.20 (.12)	.16 (.09)

Note. HMA = high math-anxious individuals; LMA = low math-anxious individuals. Standard deviations are given in parentheses.

assigned to the control condition differed in RT for high-demand word problems, $F(1, 38) = 4.87, p < .05$.

Thus, using RT as an outcome measure, we found that expressive writing reduced the performance gap between HMAs and LMAs most strongly on high-demand math problems. As seen in Table 1 (right) and below, error-rate data mirror this finding.

Error Rates

Math error rates. In the control condition, HMAs ($M = .21, SD = .13$) committed more errors on high-demand math problems than LMAs ($M = .13, SD = .06, F(1, 37) = 3.15, p = .08$). Note, however, that when test anxiety was not controlled, this simple effect was significant, $F(1, 38) = 5.65, p < .05$. In contrast, when participants were asked to expressively write before the exam, the math-anxiety gap in error rates was closed, $F(1, 37) = .97, p > .30$, though the Math Anxiety (LMAs, HMAs) \times Writing Group (expressive writing, control) interaction on high-demand math-problem error rates was not significant, $F(1, 75) = .78, p > .30$.

In contrast, we found that error rates did not differ as a function of math anxiety in either the control, $F(1, 37) = .72, p > .40$, or expressive writing conditions, $F(1, 37) = .01, p > .90$ on low-demand math problems. In addition, there was no Math Anxiety \times Writing Group interaction on low-demand math problems, $F(1, 75) = 1.07, p > .30$.

Word error rates. In both control ($p > .30$) and expressive writing conditions ($p > .20$), HMAs did not commit more errors on high-demand word problems than LMAs. Similar null results were seen for low-demand word problems ($ps > .20$). The Math Anxiety \times Writing Group interaction was not significant for either the high-demand, $F(1, 75) = .12, p > .70$, or low-demand word problems, $F(1, 75) = .00, p > .90$.

Composite z Score With RTs and Error Rates

We next sought to draw a comprehensive picture of our results by creating a measure of performance that takes both RTs and error rates into account simultaneously. Because both measures of performance are informative in real world settings (i.e., students should solve problems accurately within a given time period), we see this composite measure as the crux of our analyses. Integrating RTs and error rates into a single dependent variable is a recommended procedure (Bruyer & Brysbaert, 2011; Salthouse & Hedden, 2002), as it helps to create the most comprehensive measure of performance. One established method for creating a composite score is to average standardized RT and error-rate data (Burns, Riggs, & Beck, 2012; Lyons & Beilock, 2011; Supekar et al., 2013). To do this, we (a) standardized RT and error-rate data separately and then (b) averaged across the standardized RT and standardized error-rate scores. More specifically, we began by calculating μ s and σ s of RT for the math and word data independently (i.e., $\mu_{\text{math RT}}, \mu_{\text{word RT}}, \sigma_{\text{math RT}}, \sigma_{\text{word RT}}$). We then transformed each individual RT value X (i.e., the average RT for trials that were solved correctly) into a standardized score (z score) by subtracting the domain μ of RT and dividing by the domain σ of RT. We standardized error-rate data using the same procedure independently. The standardized RT and standardized error-rate data were then averaged to create composite z scores,¹ which served as outcome variables. In the current analyses, a higher

composite z score represented worse performance (i.e., slower RTs and higher error rates).

Math performance. As shown in Figure 1 (right), in the control condition, HMAs performed significantly worse on high-demand math problems ($M = 1.14, SD = .64$) than their LMAs ($M = .27, SD = .34, F(1, 37) = 15.88, p < .001$). However, when given an opportunity to write prior to the math exam, HMAs ($M = .63, SD = .64$) did not significantly differ from LMAs ($M = .39, SD = .55$) in their math performance for high-demand problems, $F(1, 37) = 2.64, p > .10$. Furthermore, HMAs assigned to the expressive writing condition performed significantly better than HMAs assigned to the control condition on high-demand math problems, $F(1, 41) = 8.37, p < .01$. A Math Anxiety (LMAs, HMAs) \times Writing Group (expressive writing, control) interaction on high-demand math problems confirmed that expressive writing reduced the performance gap between HMAs and LMAs, $F(1, 75) = 7.24, p < .01$.

Participants' performance on low-demand math problems (Figure 1, left) did not vary as a function of math anxiety in either the control condition, $F(1, 37) = .02, p > .80$, or the expressive writing condition, $F(1, 37) = .74, p > .30$. There was no Math Anxiety \times Writing Group interaction on low-demand math problems, $F(1, 75) = .00, p > .90$, which is in line with prior work demonstrating that performance deficits among HMAs are most apparent on math problems with high working-memory demands (Ashcraft & Faust, 1994).

Word performance. The Math Anxiety \times Writing Group interaction was not significant, $F(1, 75) = 1.49, p > .20$, on high-demand word problems, suggesting that the effects of writing condition on word performance did not vary as a function of math anxiety and writing group. However, a simple effects analysis showed that in the control condition, HMAs ($M = .85, SD = .63$) performed worse on high-demand word problems than their LMA counterparts ($M = .29, SD = .73, F(1, 37) = 4.32, p < .05$, whereas in the expressive writing condition, there were no differences between HMAs and LMAs, $F(1, 37) = .99, p > .30$. Participants' performance on low-demand word problems did not vary as a function of math anxiety in either the control condition, $F(1, 37) = 1.22, p > .20$, or the expressive writing condition, $F(1, 37) = .46, p > .50$. There was no Math Anxiety \times Writing Group interaction, $F(1, 75) = .09, p > .70$.

Given that the math- and word-problem blocks were interleaved and presented close together in time, it is possible that an anxious reaction to one problem type (e.g., HMAs and math problems) had lingering effects on performance on another problem type (i.e., word problems). That is, among participants in the control condition, HMAs' feelings of nervousness may have persisted well into the word problems, which could have lowered word performance. If this is the case, then we would expect that the effect of math anxiety on high-demand word performance should be accounted for when controlling for high-demand math performance. This is exactly what we found. The significant performance gap between

¹ RT z score = $(X_{\text{RT}} - \mu_{\text{domain RT}}) \div \sigma_{\text{domain RT}}$; error rate z score = $(X_{\text{error rate}} - \mu_{\text{domain error rate}}) \div \sigma_{\text{domain error rate}}$; composite z score = $(\text{error rate } z\text{-score} + \text{RT } z\text{-score}) \div 2$. Note that our results remain largely unchanged even if we use domain/demand-specific μ s ($\mu_{\text{low-demand math}}, \mu_{\text{high-demand math}}, \mu_{\text{low-demand word}}, \mu_{\text{high-demand word}}$) and σ s ($\sigma_{\text{low-demand math}}, \sigma_{\text{high-demand math}}, \sigma_{\text{low-demand word}}, \sigma_{\text{high-demand word}}$).

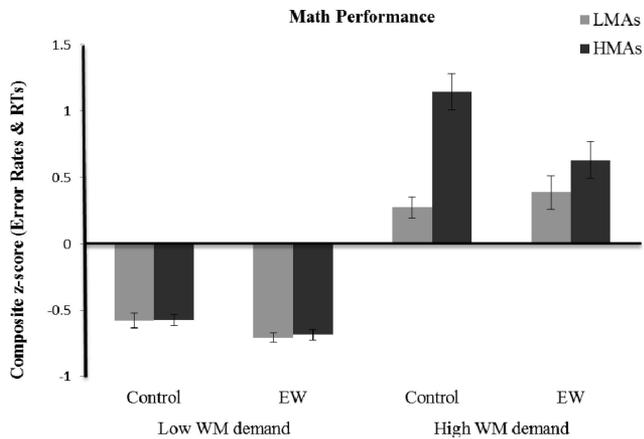


Figure 1. Math performance (where higher indicates worse performance) as a function of individuals' math anxiety (low, high), condition (control, EW) and working memory (WM) demands of the problems themselves (low, high). Error bars are standard errors(+/-1).

LMAs and HMAs on high-demand word problems reported above, $F(1, 37) = 4.32, p < .05$, was rendered nonsignificant when we took into account performance on high-demand math problems, $F(1, 36) = 1.07, p > .30$. However, the performance gap between LMAs and HMAs on high-demand math problems, $F(1, 37) = 15.88, p < .001$, remained significant even after we accounted for performance on high-demand word problems, $F(1, 36) = 11.45, p < .01$.

In summary, across several ways of analyzing our data, we consistently show that a single bout of expressive writing is an effective intervention to reduce the prevailing performance gap seen most strongly between HMAs and LMAs on high-demand math problems. Encouraging HMAs to write about their thoughts and feelings before taking a math exam helps these individuals to perform at a comparable level to their LMA counterparts on a subsequent math exam by expediting problem-solving procedures and rendering fewer errors.²

Writing Analysis

To investigate exactly how writing might relate to the performance of HMAs and LMAs, we examined the frequency of particular word categories used in participants' writing using a text-analysis software, Linguistic Inquiry and Word Count (LIWC; Pennebaker, Booth, & Francis, 2001). LIWC is a widely used computerized text-analysis program that sorts words into psychologically relevant categories as a means to calculate the degree to which people use different categories of words in their writing (Pennebaker et al., 2001). Given previous research indicating that expressing worries and use of cause and insight words are important markers of emotional processing (Ramirez & Beilock, 2011; Klein & Boals, 2001), we wondered whether the use of these categories (i.e., anxiety, cause, and insight) might be playing a role in our work as well. Table 2 shows the total number of words used, as well as the percentage of anxiety (e.g., nervous, afraid), cause (e.g., because, hence), and insight words (e.g., think, know) used by HMAs and LMAs. Though one might notice that the percent range for each category of words is low (between 0.82% and

3.35%), it is comparable with published norms (Pennebaker et al., 2001).

Among HMAs, a higher use of anxiety words was associated with better performance on high-demand math problems (i.e., the z-score composite), $r(17) = -.46, p = .05$;³ with RT data, $r(17) = -.00, p > .90$; and with error-rate data, $r(17) = -.56, p < .05$. This relationship became even stronger when cause and insight words were included together with anxiety words in the model, $r(17) = -.48, p < .05$; with RT data, $r(17) = -.48, p < .05$; and with error-rate data, $r(17) = -.19, p > .40$. There was no relation between the frequency of anxiety, cause, and insight word use and low-demand math problems, $p > .20$. Moreover, frequency of anxiety, cause, and insight words among HMAs did not predict performance for word problems that were either low or high in working-memory demand, $ps > .10$. LMAs showed no relation between use of anxiety, cause, and insight words and low or high-demand math or word problems, $ps > .30$. Taken together, these findings largely support our hypothesis that offloading anxiety-related worries through expressive writing can effectively improve the performance of HMAs whose math performance is most plagued by worry-relevant disruptions to working memory.

Discussion

When HMA individuals are tasked with solving math problems requiring high working-memory demands, they perform significantly worse than their LMA counterparts (Ashcraft & Kirk, 2001). This pattern of results has been documented even in children as young as first and second grade (Ramirez et al., 2013; Vukovic et al., 2013; Young et al., 2012), suggesting that many adult students may have a long history of suffering the deleterious effects of math anxiety. Despite the pervasive experience of math anxiety, we show that after a single bout of expressive writing, we can significantly reduce the extent to which math anxiety relates to individuals' math performance.

Why does expressive writing help to reduce the performance gap between HMAs and LMAs? We favor the possibility that expressive writing lessens the likelihood that math-related worries will capture attention during the math task (Lepore, Greenberg, Bruno, & Smyth, 2002). This idea is supported by our finding that HMAs who used more anxiety words in their writing demonstrated better subsequent math performance on the most demanding problems. Writing about performance worries may free up working-memory resources to help students better identify, differentiate, and understand their emotional experience (Gohm & Clore, 2000), which can lead to the adoption and execution of more effective emotion-regulation strategies (Boden, Bonn-Miller, Kashdan, Alvarez, & Gross, 2012; Schmeichel & Demaree, 2010).

After all, individuals spontaneously regulate their emotional experience when put in aversive situations (Lieberman, 2007;

² Multivariate analysis of covariance (MANCOVA; using RTs and error rates as DVs while controlling for test anxiety) replicated our composite z-score results. The Math Anxiety (LMAs, HMAs) \times Writing Group (expressive writing, control) interaction was significant for high-demand math problems, $F(2, 74) = 3.91, p < .05$, but not for low-demand math problems and word problems in general (low and high demand), $ps > .10$.

³ We controlled for total number of words used here. We also began this analysis by removing one extreme outlier based on Cook's distance, and the composite z score was recalculated after excluding this individual.

Table 2
Mean Percentage of Word Frequency for LMAs and HMAs

Word category	LMAs	HMAAs
Total word count	272.39 (86.01)	301.00 (95.07)
Anxiety	.82 (.53)	.87 (.89)
Cause	1.58 (.60)	1.40 (.97)
Insight	2.72 (1.15)	3.35 (1.69)

Note. HMA = high math-anxious individuals; LMA = low math-anxious individuals. Standard deviations are given in parentheses.

Volokhov & Demaree, 2010). Expressive writing may create an ideal context for promoting effective emotion understanding through the use of cognitive strategies that change the meaning of a stressful situation (Boals, 2012; Gray, Braver, & Raichle, 2002; Gross & Thompson, 2007; Moser, Most, & Simons, 2010; Ochsner & Gross, 2005). This idea is in part supported by the current and previous work showing that higher use of cause and insight words together with anxiety words may drive the benefits of expressive writing (Ramirez & Beilock, 2011). Moreover, if expressive writing helps free up working memory, this may also help emotion regulation, as working-memory availability predicts more effective emotion-regulation processes (Schmeichel & Demaree, 2010).

Another possibility is that expressive writing helps individuals to distance themselves from their immediate sources of stress, which previous research suggests is an important component in accounting for the benefits of expressive writing (Kross & Ayduk, 2011; Ochsner & Gross, 2008). More work is of course needed to understand the exact mechanisms by which expressive writing affects performance—especially since the above possibilities are not mutually exclusive. Nonetheless, at a practical level, our results demonstrate an easy and effective way to disarm the math-anxiety-poor math-performance relation. Indeed, there have been past attempts to find effective interventions for the negative outcomes of math anxiety on performance, but many of the interventions are either extensive or generally unsuccessful. For instance, previous studies implementing classroom interventions such as relaxation training and group counseling were not shown to be effective at reducing the negative effects of math anxiety on performance, despite the prolonged exposure to these interventions (see Hembree, 1990). Our work shows that one bout of expressive writing can reduce the performance gap between low and high math-anxious students.

Although the work reported here demonstrates significant benefits for HMAs, one might wonder what effects expressive writing might have on students who were never anxious to begin with. It is possible that encouraging LMAs to write about their thoughts and feelings can hurt performance by creating feelings of nervousness that might not have otherwise been present (Boals, 2012; Lang & Lang, 2011). However, we did not find evidence that supports this hypothesis: LMAs in the expressive writing condition did not differ on any of our performance measures from LMAs in the control condition, $ps > .10$ (RT, error rate, z score). Furthermore, we found that the use of anxiety words was not associated with LMAs' performance, which is in line with our interpretation that expressive writing did not negatively impact the performance of people who may not have been anxious to begin with. Thus, expressive writing tended to improve the performance of HMAs while not hurting the performance of LMAs.

Although we intentionally chose our control manipulation to mimic real-life testing situations, it is possible that the waiting period in the control condition might have incubated anxiety. Hence, an alternative explanation is that waiting may have exacerbated the effects of anxiety among math-anxious individuals as opposed to our account that expressive writing mitigated the performance gap between HMAs and LMAs. However, this claim is somewhat contradictory to previous math-anxiety work demonstrating that HMAs perform more poorly than LMAs even without a waiting period (Ashcraft & Faust, 1994; Ashcraft & Kirk, 2001; Faust et al., 1996).

The current findings speak to how parents, educators, and education policymakers should interpret and hence respond to high math-anxious students. The beliefs, perceptions, and attitudes of people charged with students' education determine the teaching methods, interaction patterns, levels of involvement, and remedial strategies that they implement with students (Brophy, 1983; Clark & Peterson, 1986; Eccles, Jacobs, & Harold, 1990; Georgiou, 1999). For instance, when teachers believe that a student lacks competence in an academic domain, they often provide the student with easier tasks and adopt lower standards, which in turn decrease the student's engagement and perceived ability in the domain (Brophy & Good, 1970; Harris & Rosenthal, 1985; Tiedemann, 2000). Furthermore, low expectations for a student's competence can lead educators to provide feedback that communicates an acceptance of the student's weakness (e.g., "It's okay, not everyone is good at math"), which can backfire and discourage the student from performing well (Rattan, Good, & Dweck, 2012). Hence, educators and parents who interpret students' struggle with math as a sign of incompetence may respond very differently from those who believe that the struggle is due to anxiety.

The work reported here helps shape this debate by showing that simply asking students to write about their thoughts and feelings before a test has a power to immediately reduce the impact that math anxiety has on students' performance. Such immediate benefits of expressive writing have the potential to help students who struggle with math anxiety to demonstrate their true competency in math during testing situations that hold significant consequences for future academic success.

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