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A Closer Look at Who "Chokes Under Pressure"☆,☆

Jason R. Sattizahn*
The University of Chicago, United States

Jason S. Moser
Michigan State University, United States

Sian L. Beilock
The University of Chicago, United States

Previous research has shown that the higher one's working memory capacity, the more likely his/her performance is to be negatively impacted by performance pressure. In the current research we examined potential explanations for this finding by assessing the relation between pressure-induced performance deficits (i.e. "choking under pressure") in math-based problem solving and individual differences in both working memory (as assessed via complex span tasks) and attentional control (as assessed via two measures from an Eriksen Flanker task). We find higher working memory only relates to "choking under pressure" when individuals were low in attentional control. These results further elucidate the mechanism by which high-pressure scenarios can lead to errors in performance and carry implications for developing effective intervention strategies to prevent poor performance in high-stakes situations.

Keywords: Working memory, Pressure, Attentional control

Not all errors are created equal. Repercussions from miscalculating a tip at dinner may be somewhat trivial, but miscalculations in a testing situation such as the ACT or GRE can be much more costly. The outcomes of high-pressure situations such as standardized testing can have a significant impact on one's academic future and career. One large factor contributing to performance in these cognitively-demanding situations is our working memory, a limited-capacity executive resource used for the immediate storage, integration and manipulation of information (Miyake & Shah, 1999). As working memory works to maintain task-relevant information, it intrinsically plays a role in resisting against information that could interfere with task performance (Kane & Engle, 2000). Relatively higher levels of working memory are associated with a number of desirable outcomes, including greater mathematics performance (Raghubar, Barnes, & Hecht, 2010) and even higher levels of general academic achievement (Alloway & Alloway, 2010).

Although an increased working memory capacity is generally associated with positive outcomes, the advantage that those higher in working memory have over those lower in working memory are not always seen. For instance, research by Kane and Engle (2000) measured susceptibility to interference during a word recall task between those low in working memory and those high in working memory. When participants' performed only a word recall task, those with a higher working memory showed a markedly lower number of task interferences compared to lower working memory individuals. However, when participants engaged in a second, attention-dividing task while performing the word recall task, participants exhibited the same number of task interferences regardless of their level of working memory. A similar pattern has been shown in high-pressure performance situations. Relative to low-pressure situations, individuals placed in high-pressure situations often show performance decrements, a phenomenon known as 'choking under pressure' (Baumeister,

☆ Author Note.

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* Correspondence concerning this article should be addressed to Jason R. Sattizahn, The University of Chicago, Psychology Department, 5848 S. University Avenue, Chicago, IL 60637, United States. Contact: sattizahn@uchicago.edu.

1984; Wine, 1971). In math problem solving, individual differences in working memory moderates this effect, such that those highest in working memory actually show the largest cognitive deficits as a result of pressure (Beilock & Carr, 2005; Gimmig, Huguet, Caverni, & Cury, 2006).

In one of the first demonstrations of the moderating role of working memory on choking under pressure, both low and high working memory participants were subjected to a high-pressure scenario involving peer pressure, monetary incentives and social evaluation. Before experiencing pressure, individuals higher in working memory showed significantly higher cognitive performance than those lower in working memory. However after experiencing pressure, cognitive performance for those higher in working memory decreases to a similar level as their low working memory counterparts. Further research suggests that this increase in error by those relatively higher in working memory is due to the working memory resources that these individuals normally rely on being compromised by thoughts or anxieties related to task performance (Beilock, Rydell, & McConnell, 2007; DeCaro, Rotar, Kendra, & Beilock, 2010; Schmader and Johns, 2003; Wang & Shah, 2014).

Although previous research shows that as working memory increases, susceptibility to performance decreases in acute high-pressure situations, it is important to point out that the effects of these results do not suggest that all individuals higher in working memory choke under pressure. When studies such as Beilock and Carr's (2005) account for cognitive performance with an interaction of working memory and pressure, the effect sizes are not extremely high (e.g. $\eta^2 = .06$). This suggests that factors other than working memory account for additional variance in cognitive performance under high-pressure conditions. Better understanding who is susceptible to pressure-induced cognitive deficits will not only shed light on the mechanisms by which performance pressure impacts skill execution, but also inform the best interventions to ensure optimal performance when it matters most.

One way to understand variation in choking under pressure as a function of working memory is to dissect how researchers have chosen to characterize working memory in the first place. As previously mentioned, working memory is commonly cited as a singular cognitive construct measuring the relative ability to store task-relevant information and inhibit against task-irrelevant information. However, recent evidence suggests that standard indices of working memory reflect an inter-relationship of primary memory, secondary memory and attentional control for storage and maintenance of task information (Shipstead, Lindsey, Marshall, & Engle, 2014). By comparing over 20 separate measures of executive functioning, Shipstead and colleagues (2014) found that commonly used complex span working memory tasks (e.g. an Operation Span task) do relate to measures of attentional control (e.g. an arrow-based flankers task), as attentional control likely acts as a way to maintain information that has transitioned from primary to secondary memory.

We hypothesize that variability in attentional control may alter the amount of interfering information allowed into working memory storage, thus affecting the degree to which working memory resources are compromised during a high-pressure task. For instance, a relatively higher degree of attentional control may prevent task-irrelevant information from co-opting working memory resources, and in turn eliminate a relationship between working memory and pressure-induced performance deficits. In effect, using solely complex span measures of working memory to predict who will choke in high-pressure scenarios may mean we are missing explainable differences that attentional control can provide. Therefore, in the current work we attempt to replicate Beilock and Carr's (2005) choking under pressure finding by showing that higher levels of working memory relate to larger deficits in cognitive performance due to pressure, while we additionally collect measures of attentional control. The goal is to determine if both working memory capacity and attentional control interact to determine who is susceptible to choking under pressure.

We chose an arrow-based flankers task to measure attentional control. Although previous studies have shown a relationship between working memory capacity and measures of attention recorded from flanker tasks (Heitz & Engle, 2007; Redick & Engle, 2006), flanker tasks used have varied greatly, and separating what specific functions of attention these RT measures represent is problematic. Therefore, we used two separate RT measures from our flanker task to index attentional control and test if either measure of attention altered the relationship of working memory and choking under pressure. First, we used a comparison of response times (RTs) on trials with interfering information (incongruent) to RTs on trials without interfering information (congruent; i.e. the Flanker Effect; Sanders & Lamers, 2002). Although greater differences in this "inhibition" measure have been related lower working memory in the past (see Redick & Engle, 2006), RT difference scores can be incredibly unreliable (Lord, 1963). Therefore, we also analyzed flanker RTs across all trials (congruent + incongruent). We reason that if participants are matched on flanker accuracy, then lower overall RTs indicate a relatively increased ability to sustain attention to the task at hand throughout the course of the flanker task.

We first looked to test if higher working memory scores related to higher attentional control as indexed by either of our flanker RT measures (Kane & Engle, 2000; Redick & Engle, 2006). More importantly, however, we hypothesized that the relationship between working memory and cognitive performance under pressure would be altered by levels of attentional control, as indexed by either of our flanker RT measures. Overall, the decrease in cognitive performance due to pressure should grow larger as working memory increases, replicating the research of Beilock and Carr (2005). However, attentional control may alter this relationship. When attentional control is lower, higher working memory should predict decreases in performance due to pressure. Task-irrelevant information stemming from our pressure manipulation is likely to be allowed into working memory, in turn decreasing cognitive performance those higher in working memory. When attentional control is higher, the relation between working memory and performance under pressure may not be as robust, as higher attentional control should prevent pressure-induced worries from co-opting working memory resources.

Method

Participants

Data was collected continuously through one complete year; at the end, a total of 95 participants had been collected. Exclusion from the data set occurred if participants had <80% on the mathematical and sentence-comprehension portion of the working memory tasks (5 removed), exhibited flanker performance 3SDs outside the mean or below 50% for congruent trials (4 removed) or failed to complete the working memory tasks (3 participants removed). Therefore, a final count of 83 participants' (35 male) data is included in the present analysis.

Participants were recruited from both the greater Chicago, IL ($N = 68$) and Lansing, MI ($N = 15$) metropolitan areas (age range 18–35yo; $M = 23.19$, $SD = 4.52$) surrounding the University of Chicago and Michigan State University campuses, respectively. Participants' working memory scores are calculated as an average of two working memory tasks: an automated Operation Span (OSPAN) task (Turner & Engle, 1989; Unsworth, Heitz, Schrock, & Engle, 2005) and an automated version of Daneman and Carpenter's (1980) Reading Span (RSPAN) task. Both working memory tasks require participants to solve either a sequence of mathematical operations (OSPAN) or sentence-comprehension exercises (RSPAN), while in between each trial a letter is presented on the screen. At the end of a sequence of trials, participants were required to recall, in perfect order, the letters that had been presented during the previous sequence of math or reading exercises. In either span task, each sequence ranged from 3 to 7 trials, requiring participants to recall strings of 3 to 7 letters. A participant's final OSPAN and RSPAN score reflects the total number of letters which were recalled on perfectly recalled trials (i.e. absolute score; out of a possible 75). Because working memory scores were negatively skewed (see Figure 1), a square root transformation was performed on averaged span scores ($M = 6.79$, $SD = 1.45$).

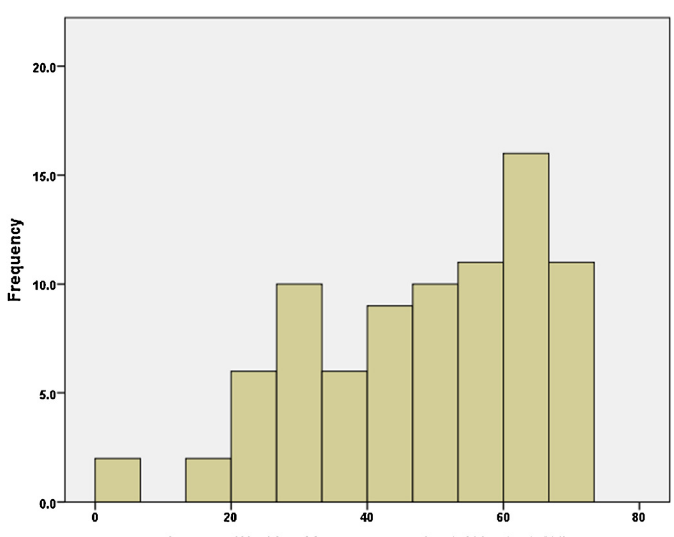

Figure 1. Histogram of average WM scores.

Procedure

Session 1. Prior to arrival in the laboratory, participants responded to a series of online questionnaires including a report of demographic information and the trait portion of the State-Trait Anxiety inventory (STAI; Spielberger & Gorsuch, 1983). Additional questionnaires were included for the purpose of obscuring the connection between anxiety and our study, but these are not analyzed any further.

Upon arriving to the laboratory, participants were tested one at a time. After providing written consent, participants were seated in front of a computer and instructed to answer a set of questionnaires. Included within these was the state portion of the STAI (Spielberger & Gorsuch, 1983), affording us a baseline measure of state anxiety which will be compared to state anxiety ratings measured immediately after our pressure induction. Once again, additional surveys were collected in order to obscure the link between anxiety and the current study, but these will not be analyzed any further.

Session 1 – Flanker Task. Next, participants completed an arrow-based flankers task (Eriksen & Eriksen, 1974) presented using E-prime software (Psychology Tools, Inc.). In this task, participants judge the direction of a center arrow placed within a series of five total arrows. Arrows only pointed either leftwards or rightwards, and within the series of arrows, the center arrow was either congruent (e.g., <<<<<) or incongruent (e.g., <<><<) with the arrows flanking it on either side. Left and right responses were indicated by pressing "A" and "L" on the keyboard, respectively. Each trial began with the presentation of a fixation cross for 100 ms, followed by the presentation of five congruent or incongruent arrows for 100 ms. The subsequent inter-trial interval varied from 800 to 1200 ms, during which a fixation cross was presented. After 40 trials, a break slide appeared and informed participants of a discretionary break before beginning the next set of trials. A total of 15 blocks of 40 trials were administered (600 trials altogether).

Session 1 – Modular Arithmetic & Pressure Induction. In order to examine the impact of a high-pressure scenario upon cognitive performance, we next enacted a method previously outlined in Beilock and Carr (2005). Baseline cognitive performance was first measured using 40 trials of Gauss' (1801) modular arithmetic. In modular arithmetic, participants make judgements about the truth value of mathematical statements such as, "$121 \equiv 94 \pmod 3$." Judging the problem requires subtracting the second number from the first (i.e. 121–94) and subsequently dividing the difference by the last number (i.e. $27 \div 3$). The dividend in this case is a whole number (i.e. 9), so the modular arithmetic problem is judged true. When the dividend is not a whole number, the modular arithmetic problem is judged false. A modular arithmetic problem in which the first number in the sequence is large (>20) or the first subtraction step requires a carrying operation (similar to our example above) is high in working memory demand. However, problems such as, "$5 \equiv 2 \pmod 3$," require no carrying operation and are defined as low working memory demand. Since modular arithmetic is a mathematical task novel to participants regardless of math experience, it is an excellent task for measuring cognitive

Table 1
Descriptive Statistics of Pre- and Post-pressure Manipulation Data

	STAI		Low Demand Math RTs		High Demand RTs		Low Demand Math Acc		High Demand Math Acc	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Pre-pressure	35.34	9.39	2545.90	835.71	8487.96	3419.00	.9729	.038	.8718	.1030
Post-pressure	40.51	11.15	2068.33	659.47	7563.34	3409.54	.9735	.036	.8513	.1028

performance. Our modular arithmetic task included 40 trials, 20 of which were of low working memory demand and 20 were of high working memory demand.

Following the first modular arithmetic task, participants were exposed to a high-pressure scenario that has been reliably demonstrated to increase feelings of pressure, anxiety, and induce performance deficits across a range of tasks. The pressure induction requires performing a second block modular arithmetic problems in the context of monetary incentive (≥20% improvement on modular arithmetic leads to a $10 bonus), peer pressure (failure to improve modular arithmetic accuracy by ≥20% causes another participant to not receive bonus) and social evaluation (performance is recorded for local teachers and professors to examine). Once these terms of the second block of modular arithmetic were explained, participants completed an additional 40 modular arithmetic problems unique from the first block. Again, 20 problems were low in working memory demand and 20 high in working memory demand. Blocks 1 and 2 of modular arithmetic were counterbalanced across all participants, and modular arithmetic stimuli were presented using E-prime software (Psychology Tools, Inc.).

A second state-anxiety measure (STAI; Spielberger & Gorsuch, 1983) immediately followed block 2 of modular arithmetic to serve as a comparison to the state anxiety measure collected prior to the pressure induction. The post-pressure anxiety questionnaire did not save for a single participant, explaining the variation in degrees of freedom within the analysis on STAI below.

Finally, scheduling for Session 2 occurred at least two days after Session 1. Participants were told that this was because of the time required to analyze modular arithmetic data in order to calculate final reimbursement for the study, when in actuality we wanted to guarantee that the pressure induction in Session 1 did not impact results in Session 2. Importantly, participants were also told that performance in Session 2 held no bearing on final reimbursement for the study.

Session 2. The purpose of Session 2 was to collect participants' working memory scores. Upon arriving to the lab, participants completed an automated version of both the OSPAN and RSPAN tasks. Once completed, a short interview was conducted by the experimenter in which participants were asked (a) to what extent they felt pressured to perform well during Session 1 and (b) what they believed was the purpose of the experiment. While this interview functioned to flag participants expressing explicit knowledge of either the experiment's purpose or previous research pertaining to this same experimental design, no participants were removed from analyses for this reason. Participants were then debriefed and paid $25 regardless of their modular arithmetic performance within Session 1.

Results

Pressure Induction Manipulation Check: STAI

Means and standard deviation for pre- and post-pressure anxiety (STAI) ratings are located in Table 1. A repeated measures ANOVA showed that our pressure manipulation did increase participants' reported levels of anxiety ($F(1,81) = 43.42, p < .01, \eta^2 = .35$). Correlation analyses show no relationship of pre-anxiety, post-anxiety or an anxiety difference score (post-STAI minus pre-STAI) with working memory, any measure of flanker accuracy or any measure of flanker RT (all correlations at $p > .10$).

WM-Demanding Cognitive Performance

Math Accuracy. Means and standard deviation for all pre- and post-pressure modular arithmetic performance are located in Table 1. Problems high in working memory demand were performed less accurately than problems low in working memory demand. In an attempt to replicate findings by Beilock and Carr (2005) showing that under pressure, working memory demanding cognitive performance is most likely to decrease for those relatively higher in working memory, we first performed a repeated measures ANCOVA (Pressure: low, high) analyzing the accuracy of high-demand math while using working memory scores as a continuous between-subjects variable. There was a significant two-way interaction of pressure and working memory ($F(1,81) = 4.29$, $p < .05$, $\eta^2 = .05$).[1] To make it clear how differences in working memory related to changes in cognitive performance before and after pressure, we performed a median split in our WM scores. Using these two groupings, a comparison of pre- to post-pressure high-demand math accuracy revealed no significant change for those lower in working memory ($t(40) = -1.63$, n.s.). However, for those higher in working memory, there was a significant decrease in high-demand math accuracy ($t(41) = 2.30$, $p < .030$).

We further explored working memory's relationship to performance by creating a math difference score in which we subtracted pre-pressure from post-pressure high-demand math

[1] The same ANCOVA accounting RTs of correct, high-demand math problems revealed a main effect of pressure ($F(1,81) = 17.03$, $p < .01$, $\eta^2 = .17$) but no interaction with working memory ($p > .05$), indicating that the interaction of pressure and working memory in accounting for accuracy was not the result of a speed-accuracy trade-off.

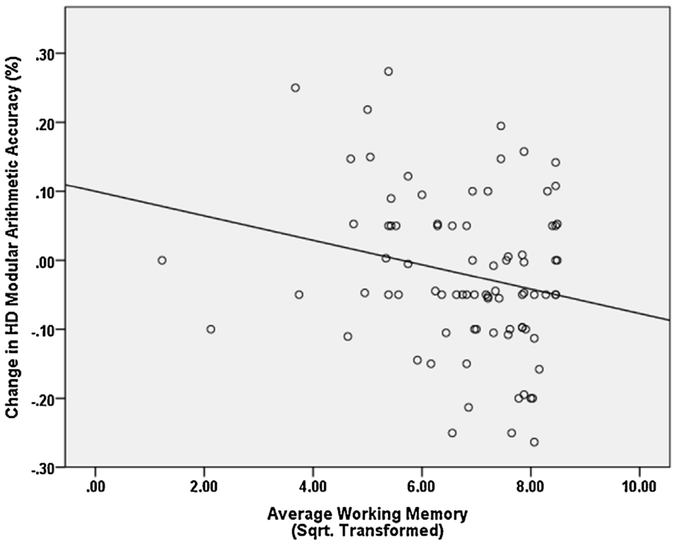

Figure 2. Scatterplot of working memory and change in modular arithmetic due to pressure. Scatterplot showing the relationship of working memory with the change in high demand (HD) modular arithmetic accuracy (%) due to pressure; as scores were calculated as post-pressure accuracy minus pre-pressure accuracy, a negative change score indicates that performance became worse after experiencing pressure.

accuracy. Although working memory correlated to neither pre-pressure accuracy ($r = .17$, $p = .12$) nor post-pressure accuracy ($r = -.08$, $p = .50$), working memory did significantly correlate to the change in high-demand math accuracy ($r = -.24$, $p < .05$). Again, this reflects the above finding that as participants' working memory increased, there was a larger decrease in working memory demanding cognitive performance due to our pressure manipulation (see Figure 2).

Math RTs. The RTs for correct math problems were analyzed in a 2 (Pressure: low, high) × 2 (Demand: low, high) ANOVA. A main effect of demand revealed that RTs were much faster for low demand problems compared to high demand problems ($F(1,81) = 375.37$, $p < .01$, $\eta^2 = .82$), a main effect of pressure showed that RTs were faster after our pressure induction ($F(1,81) = 23.74$, $p < .01$, $\eta^2 = .23$) and an interaction of pressure and demand ($F(1,81) = 5.38$, $p < .03$, $\eta^2 = .06$) revealed that pressure increased the speed of high demand modular arithmetic trials (by 1073.9 ms) more than it did low demand modular arithmetic trials (by 462.75 ms).

Flanker Performance

A complete table of means and standard deviations for both flanker accuracy and RTs are reported in Table 2.

Flanker Accuracy. Flanker accuracy was first analyzed in a repeated measures ANOVA to compare congruent and incongruent trial types, showing that congruent flanker trials ($M = .95$, $SD = .05$) were much more accurate than incongruent trials ($M = .88$, $SD = .09$; $F(1,82) = 96.94$, $p < .001$, $\eta^2 = .54$). Neither congruent nor incongruent flanker accuracy correlated with working memory (both $p > .41$).

Flanker RTs. Flanker RTs were similarly analyzed in a repeated measures ANOVA to compare congruent and incongruent trial types, showing that congruent flanker trials ($M = .95$, $SD = .05$) were much more accurate than incongruent trials ($M = .88$, $SD = .09$; $F(1,82) = 308.39$, $p < .001$, $\eta^2 = .79$). Working memory did not correlate with flanker RTs for congruent trials, incongruent trials or a difference score between the two trial types (all $p > .07$).

Indices of Attentional Control from the Flanker Task. Our first index of attentional control was a difference score that subtracted the RTs on congruent trials from RTs on incongruent trials. For this measure we used only correct flanker trials in order to mirror previous research showing that a higher working memory relates to lower flanker RT difference scores (and assumed higher attention; Redick & Engle, 2006). Within our data, although this flanker difference measure did not significantly relate to working memory, the relationship was marginal and in the expected direction ($r = -.19$, $p > .09$).

Our second index of attentional control was simply comprised of flanker RTs across all trials (congruent + incongruent). We reason that if participants are matched on flanker accuracy, then lower overall RTs indicate a relatively increased ability to sustain attention to the task at hand throughout the course of the flanker task. This may be especially so given our lengthy flanker task, as it consists of over twice the amount of trials previously used to compare working memory scores to flanker RT measures (see Heitz & Engle, 2007; Redick & Engle, 2006). Similar to our first attentional control measure, overall flanker RTs did not significantly relate to working memory, but the relationship was marginal and in the expected direction ($r = -.19$, $p > .09$).

Pressure, Working Memory and Attentional Control

The first goal of this research was to replicate that individuals higher in levels of working memory are more susceptible to pressure-induced decreases in working memory demanding cognitive performance, a finding we confirmed and described above. Our second goal was to explore if measures of attention control interact with working memory to further predict who would be most susceptible to choking under pressure. We chose a multiple linear regression (MLR) to predict the change in working memory demanding cognitive performance due to pressure (post- minus pre-pressure high-demand math accuracy) using the independent variables of working memory, attention and an interaction of the two. As we remain agnostic as to which of our two attention control measures (if any) may interact with working memory to account for pressure-induced cognitive deficits, we performed a separate MLR for either of our two attentional control measures.

Our first MLR model predicted the change in high-demand modular arithmetic accuracy using working memory (square root transformed), our flanker RT difference score and an interaction of the two. All variables were mean-centered before being included in the model. This regression model did not significantly account for variance in pressure-related cognitive performance ($F(3,79) = 1.55$, $p = .21$) and will not be analyzed further.

Our second MLR model predicted the change in high-demand modular arithmetic accuracy using working memory

Table 2
Correlation Matrix with Descriptive Statistics

	Mean	SD	Correlations 1	2	3	4	5	6	7	8
1. Working Memory (sqrt)	6.79	1.45	1							
2. HD Math Difference Score	−.02	.11	−.224*	1						
3. Flanker Acc (C)	.9497	.0513	.090	.049	1					
4. Flanker Acc (I)	.8793	.0887	.073	.198	.687*	1				
5. Flanker RT (C)	403.86	50.44	−.196	.160	−.059	.267*	1			
6. Flanker RT (I)	436.86	52.75	−.171	.126	.031	.307*	.944*	1		
7. Flanker Difference Score	38.52	23.36	.185	−.039	.150	.013	−.069	.205	1	
8. Overall Flanker RTs	420.07	50.87	−.186	.144	−.013	.292*	.985*	.987*	.072	1

Note: (C) denotes congruent trials, (I) denotes incongruent trials.
* $p < .05$.

Table 3
Full Model of the Multiple Linear Regression (MLR)

Coefficients	Unstandardized coefficients *B*	Std. error	Standardized coefficients Beta	t	Sig.
(Constant)	−.027	.013		−2.181	.032
Working Memory	−.011	.009	−.140	−1.247	.216
Overall Flanker RTs	.000	.000	.143	1.301	.197
WM ∗ Overall Flanker RTs	.000	.000	−.227	−2.043	.044

The model significantly accounted for over 7% of the variance in our DV (change in cognitive performance due to pressure; $R^2 = .108$, Adj. $R^2 = .074$, $p < .03$).

(square root transformed), overall flanker RTs and an interaction of the two. Again, all variables were mean-centered before being included in the model. This regression model significantly accounted for over 7% of the variance in pressure-related cognitive performance, ($F(3,79) = 3.2$, $p < .03$; $R^2 = .11$, Adjusted $R^2 = .074$). Multicollinearity was not an issue within our model, as the variance inflation factor did not exceed (VIF < 1.2) for any of our independent variables. In accounting for pressure-related cognitive performance, the predicted two-way interaction between working memory and our measure of attentional control was significant ($\beta = -.23$, $t = -2.04$, $p < .05$). The complete regression model can be seen in Table 3. To visualize how working memory and attentional control interacted to account for cognitive performance, we predicted the change in cognitive performance due to pressure when the means of working memory and attentional control were one standard deviation either above or below the mean (Aiken, West, & Reno, 1991). As shown in the visualization (Figure 3), this measure of attentional control did alter the relationship we found between working memory and cognitive performance under pressure. When low in attentional control, increases in working memory related to larger decreases in cognitive performance due to pressure. However, for individuals high in attentional control, this was negligible. We further confirmed these findings by analyzing this two-way interaction in a test of simple slopes, finding that the relationship of working memory and the change in cognitive performance due to pressure only significantly differed from zero when individuals were low in this measure of attentional control ($\beta = -.04$, $t = -4.10$, $p < .05$), but not when individuals were high in attentional control ($\beta = .01$, $t = 1.61$, $p = .11$).

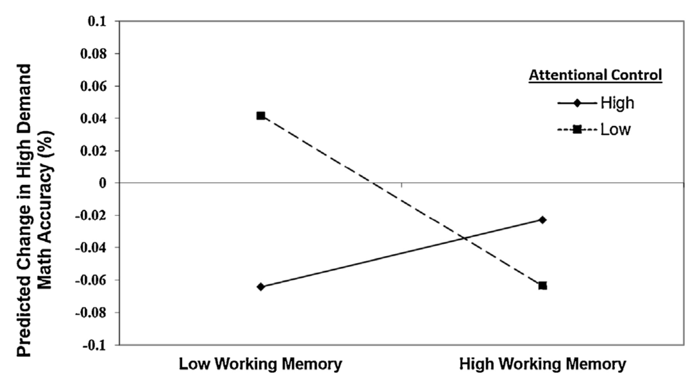

Figure 3. Visualization of two-way interaction from multiple linear regression. Although continuous in the regression model, we used working memory and attentional control at ±1 SD from their mean to visualize our two-way interaction in accounting for pressure-induced change in cognitive performance; predicted accuracy reflects a difference score (high pressure minus low pressure), meaning that a lower score indicates that math performance worsens after experiencing pressure.

Discussion

The current study replicates previous work showing individuals higher in working memory are significantly more likely to have their cognitive performance decline due to experiencing high pressure situations. We further extended these findings by showing that this relationship of working memory and cognitive performance under pressure changes based upon attentional control. When participants' attentional control was low, an increased working memory related to an increase in pressure-induced error. However, there was no relationship between working memory and cognitive performance under pressure when this measure of attentional control was high. All together, these findings suggest that when experiencing high pressure situations, differences in attentional control may alter the amount of interfering information allowed into working memory storage. When attentional control is low, individuals typically reliant on their higher working memory resources for advanced problem solving see decreases in their cognitive performance.

It is important to address the overall relationship of working memory and attentional control found in the current study. Although both attentional control measures marginally related to working memory, flanker RT measures in the past have shown a much stronger relationship to measures of working memory. For instance, Redick and Engle (2006) showed that high working memory individuals exhibited significantly smaller differences in RTs between incongruent and congruent flanker trials, as well as faster flanker RTs across congruent trials and incongruent trials compared to individuals low in working memory. Our lack of finding such a strong relationship between working memory and flanker measures of attentional control may be explained by particular differences between our study and previous studies. For instance, the flanker task used in our experiment consisted of nearly twice as many trials as other studies that have compared flanker RTs to working memory scores (Heitz & Engle, 2007; Redick & Engle, 2006). Perhaps this repetition impacted the flanker task such that our measures of attentional control became more similar across participants as the task continued. Additionally, both Heitz and Engle (2007) and Redick and Engle (2006) analyzed the relationship of attentional control and working memory by dichotomizing participants into low and high working memory groups in an individual differences approach. However, in the current research we analyzed working memory as well as attentional control as continuous variables in order to predict changes in cognitive performance surrounding high pressure experiences.

Of consideration is that only one measure of attentional control from our flanker task, overall flanker RTs, significantly interacted with working memory to account for cognitive performance under pressure. In terms of a specific mechanism of attention, it is problematic to truly delineate how this measure of attentional control differs from our flanker RT difference measure. And with the current data set, it is nearing impossibility to understand why it was solely this measure of attentional control that interacted with working memory to account for cognitive performance. However, the purpose of this study was to replicate the previously found relationship between working memory and choking under pressure, and further test if attentional control alters this relationship. Future studies analyzing pressure-related cognitive performance could benefit from using comprehensive measures of attentional control that aid in discerning between different mechanisms of attentional control.

Practical Application

At the root of any examination of human error is the drive to decrease its negative impact on our lives, and this current research is no different. Our results not only further explain the possible mechanism behind pressure-induced performance errors, but also shed light on additional ways by which we may alleviate them. Specifically, the current data suggest two possible intervention strategies for lessening pressure's impact on cognitive performance: (1) attempt to decrease the anxieties, thoughts or worries that may co-opt an individual's working memory resources, or (2) attempt to increase an individual's levels of attentional control, allowing consistent focus away from thoughts intrusive to a task at hand.

The former strategy has recently proven effective through utilization of expressive writing, a clinical technique by which individuals write freely about their thoughts regarding a stressor they may soon face. Because expressive writing proved beneficial in lowering negative thoughts in clinically anxious and depressed patients (Graf, Gaudiano, & Geller, 2008), a study by Park, Ramirez, and Beilock (2014) employed expressive writing to individuals both low and high in math anxiety prior to taking a math task. On working memory demanding math problems, high math anxious individuals who wrote expressively before the math task showed significantly lower error rates than high math anxious individuals in the control group (see also, Ramirez & Beilock, 2011; Frattaroli, Thomas, & Lyubomirsky, 2011 for further evidence regarding the benefits of expressive writing in high-stakes situations). Expressive writing likely eliminated the negative thoughts or worries that would otherwise deplete working memory resources, thereby decreasing errors made throughout the task.

Application of strategies used to increase attentional control is of great interest to researchers as of late, and the current study would suggest that this may be the most efficient strategy to curb pressure-induced deficits within higher working memory individuals. Interventions have previously utilized mindfulness training (Jha, Krompinger, & Baime, 2007), types of meditation (Tang et al., 2007) and even exposure to nature (Berman, Jonides, & Kaplan, 2008) to increase levels of attentional control and boost cognitive performance. Specific to pressure-induced cognitive deficits, research by DeCaro and colleagues (2010) decreased errors on cognitive tasks by orienting participants' attention to specific task-related steps. The researchers showed that individuals who controlled their attention by verbally speaking aloud the steps necessary to solve a series of cognitive problems showed markedly fewer errors on a working memory demanding task compared to participants who did not direct their attention to these steps through verbally speaking out loud.

Although these interventions have shown promise, it is still an open question as to the effects of these intervention strategies on individuals highest in working memory. Often, intervention strategies are thought of in terms of "one-size-fits-all." However, the current research suggests that intervention strategies which operate on orienting attentional control would be particularly beneficial for those relatively higher in working memory but lower in attentional control, as we show in the current research that it is these individuals most susceptible to seeing decreases in performance due to pressure. Identifying who is most prone to "choke under pressure" on cognitively demanding tasks, and why, helps shed light on who will benefit from targeted interventions designed to improve performance when it matters most.

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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