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About the Math Performance in Stressful Situations

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ABSTRACT

Whether because individuals are made aware of negative stereotypes about how they should perform or are in a high-stakes testing situation, a stressful environ- ment can adverselyaffect the success people have in solving math problems. I review work examining how unwanted failure in math occurs and individual differences in those most likely to fail. This work suggests that a high-stress situation creates worries about the situation and its consequences that compete for the working memory (WM) normally available for performance. Consequently, the performance of individuals who rely most heavily on WM for successful execution (i.e., higher-WM individuals) is most likely to decline when the pressure is on.

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INTRODUCTION

Solving a math problem like ''(32 — 18) ÷ 7 5 ?'' in one's head involves several steps. First, one must compute the answer to ''32 — 18 5 ?'' Second, one must hold this answer in memory and divide by 7. Although the attention, memory, and computational processes that support these types of calculations have been investigated, less work has addressed how such calculations are affected by common types of real-world situations in which mathematical thinking takes place. How might being in an im- portant testing situation affect performance of the above prob- lem? What about working through the problem at the chalk board while an entire class looks on? Or, what if a female student performed this calculation after being told ''everyone knows girls can't do math''?

Although individuals may be motivated to perform well in such stress-laden situations, these circumstances often cause individuals to perform at their worst. The expression ''choking under pressure'' is used to describe what happens when people perform more poorly than expected given their skill level pre- cisely because there are large incentives for optimal performance and highly negative consequences for poor performance (Beilock & Carr, 2001). And, the term stereotype threat (ST) describes situations in which awareness of a negative stereotype about how one's social group should perform (e.g., ''girls can't do math'') produces less-than-optimal execution (Steele, 1997). Studies of choking and ST have yielded similar conclusions about how suboptimal performance in math arises. My col- leagues and I are interested in understanding why these per- formance decrements occur and for whom they are most likely. Our goal is to leverage this knowledge to devise training regi- mens, performance strategies, and testing environments that alleviate math failure.

LITERATURE REVIEW

Why Does Failure In Math Occur?

For several decades, researchers have investigated why indi- viduals who are overly anxious about math perform poorly at it, despite often showing competency in other domains. One explanation is that math-anxious individuals were never math proficient to begin with. However, while there is usually a neg- ative relation between math anxiety and math skill, this is not the entire story. Ashcraft and Kirk (2001) have shown that part of highly math-anxious individuals' poor performance stems from anxiety-induced depletion of the cognitive resources that support complex math tasks.

The work described here focuses on how situation-induced feelings of pressure can undermine math performance in anyone, not just why dispositionally math-anxious individuals perform poorly. Nonetheless, similar to the idea that math anxiety robs one of the cognitive capacity needed to successfully execute math tasks, our findings suggest that suboptimal math perfor- mance in stress-laden situations arises because worries about the situation compete for the working memory (WM) available for performance. WM is a short-term system involved in the control, regulation, and active maintenance of a limited amount of information immediately relevant to the task at hand (Miyake & Shah, 1999). If the ability of WM to maintain task focus is disrupted, performance may suffer. We refer to this as the *distraction account* of failure because we believe that stress-la- den environments essentially place individuals in a dual-task situation: Task execution and performance-related worries vie for the WM capacity that, in less stressful circumstances, could be devoted solely to math.

To understand how situation-induced pressures undermine math performance, my colleagues and I have created a high- stakes testing environment in our laboratory. We have used the mathematician J.C.F. Gauss's *modular arithmetic* (MA) as a test bed. MA involves judging the truth value of equations [e.g., 34 Ξ 18 (mod 4)]. To do this, one subtracts the second number from the first number (''34 — 18''). This difference is then di-vided by the last number (''16 ÷ 4''). If this division step results in a whole number (here, 4), the statement is *true*. Problems with remainders are *false*. Problem validity can also be determined by dividing the first two numbers by the mod number. If the same remainder obtains (here, 34 ÷ 4 and 18 ÷ 4 both have re- mainders of 2), the equation is *true*. We usually teach partici- pants the first method mentioned above for solving MA problems in our studies.

It is important to understand how pressure compromises performance on tasks like MA because careless mistakes on the types of computations inherent in MA contribute to less-than- optimal performance in many standardized math testing situa- tions. Moreover, even problems that go beyond the conceptual demands of MA (at least, as we use MA) often require mental calculations similar to those needed to compute MA answers. Thus, understanding how stressful situations compromise even relatively simple calculations will shed light on unwanted per- formance decrements.

In an initial study (Beilock, Kulp, Holt, & Carr, 2004), indi- viduals solved MA problems that varied as a function of whether the first problem step (i.e., the initial subtraction step) involved large numbers (greater than 10) and borrowing from the tens column (a borrow operation; e.g., ''45 — 27''). Larger numbers and borrow operations involve longer sequences of steps and require maintenance in memory of more intermediate products, placing greater demands on WM (Imbo, Vandierendonck, & Verguewe, 2007). If pressure impacts WM, then performance should be more likely to decline on high-WM demanding problems [e.g., 51 Ξ 29 (mod 4)] in comparison to low-WM-demanding problems [e.g., 6 Ξ 3 (mod 3)].

To test this, some individuals (assigned to a low-pressure group) were simply told to try their best. Others were given a scenario based on common pressures (e.g., monetary incentives, peer pressure, social evaluation). Participants were informed that if they performed at a high level on the math task, they would receive some money. Participants were also told that this award was dependent on the good performance of both themselves and a partner they were paired with—a ''team effort.'' Participants were then informed that their partner had completed the experiment and improved. Thus, the current participant was entirely responsible for winning (or losing) the money. Participants were also told that their performance would be videotaped and that teachers and students would watch the tapes.

Not surprisingly, this scenario increased participants' re- ported feelings of pressure and reduced their math accuracy relative to individuals in the low-pressure group. However, performance decrements were limited to problems highest in WM demands. This suggests that pressure exerts its impact by taxing WM resources necessary for demanding computations.

Although this work implicates WM in math failure, it does not tell us what exactly pressure-filled environments do to WM to produce suboptimal performance. As previously mentioned, the distraction account suggests that situation-related worries reduce the WM available for performance. If so, then math problems heavily reliant on the resources that worries also co- opt should be most susceptible to failure. Thus far, we have conceptualized WM as a general-capacity system—meaning that it supports cognitive operations regardless of the type of information involved. However, there is also work suggesting that certain components of WM may be devoted more to either verbal processes (e.g., inner speech and thinking) or visuo- spatial processes (e.g., holding a visual image in memory).

If worries tax verbal components of WM, and if math problems can be differentiated by the demands they make on verbal versus visuo-spatial resources, then performance on problems heavily reliant on verbal resources should be especially compromised under stress. Of course, this does not mean that tasks with spatial demands (e.g., mental rotation) will show no signs of failure (especially if, for example, one concocts visual images of feared consequences). Rather, if verbal ruminations and worries are a key component of stress-induced failure, then performance decrements should be most pronounced in tasks that depend heavily on WM and especially verbal aspects of this system.

Beilock, Rydell, and McConnell (2007) examined this hy- pothesis using a different type of stress, negative-performance stereotypes. We asked whether women at a selective Midwestern university who were reminded of the stereotype that men are better at math than women would perform worse on MA than women who did not receive this information (i.e., whether neg- ative stereotype presentation would elicit ST). With respect to gender and math, sex differences in problem solving have been shown to emerge most strongly at higher age levels and in highly select samples (e.g., college-bound high-school students; Hyde, Fennema, & Lamon, 1990). Thus, a high-achieving college population seemed especially appropriate to study.

We were particularly interested in whether performance on math problems that relied more heavily on verbal resources than visuo-spatial resources would be differentially harmed. Although all arithmetic problems involve general WM resources, Trbovich and LeFevre (2003) demonstrated that math problems presented in a horizontal format (Fig. 1) depend heavily on phonological or verbal resources, because individu- als maintain problem steps in memory verbally (e.g., repeating them in their head). Math problems presented in a vertical format (Fig. 1) rely more on visuo-spatial resources, because individuals tend to solve vertical problems in a spatial mental workspace similar to how they solve such problems on paper.

Vertical MA Problems : 52 ≡ 24 (Mod 3)

Fig. 1. Example of vertically oriented and horizontally oriented modular arithmetic (MA) problems. Adapted from "Stereotype Threat and Working Memory: Mechanisms, Alleviation, and Spillover," by S.L. Bei- lock, R.J. Rydell, & A.R. McConnell, 2007, *Journal of Experimental Psychology: General*, *136*, p. 261. Copyright 2007, American Psychological Association. Adapted with permission.

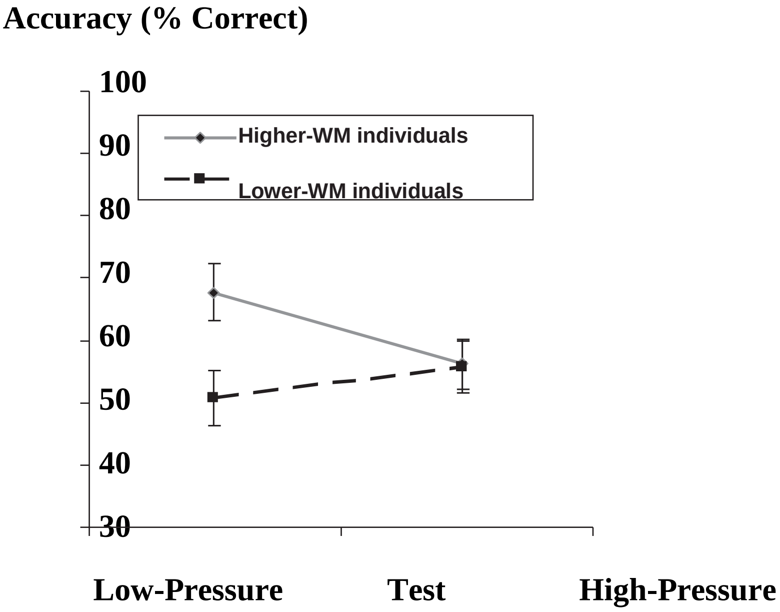

Fig. 2. Math accuracy for high-working-memory (WM)-demanding modular arithmetic (MA) problems for lower-WM individuals and for higher-WM individuals in the low-pressure and high-pressure tests. Error bars represent standard errors. Adapted from Beilock & Carr (2005).

METHODOLOGY

If horizontally oriented math problems recruit verbal resources that vertical problems do not, and if ST induces an inner monologue of worries that relies heavily on verbal WM, then horizontal problem performance should be more negatively impacted by ST than vertical problem performance is. This is what we found. Women under ST performed more poorly than controls not receiving the negative stereotype. However, this poor performance was limited to horizontal problems heavily reliant on phonological aspects of WM. Performance on vertical problems did not differ as a function of group. Women under ST also reported worrying more about the experimental situation and its consequences than controls did.

In a second experiment, women again performed horizontal math problems after being reminded of math gender differences. Everyone then performed a second task that required the maintenance of either verbal or spatial information in memory. If ST most strongly impacts verbal operations by situation-related worries, and if this does not immediately subside when perfor- mance on the stereotyped task is finished, then individuals should perform more poorly on a verbal (vs. a spatial) task fol- lowing ST in math. In essence, ST may ''spill over'' onto tasks not implicated by the negative stereotype.

Women performed poorer on the verbal-memory task than on the spatial-memory task following ST. Moreover, those who performed the poorest under STon math also showed the poorest performance on the subsequent verbal task—a correlation be- tween math performance under ST and verbal-memory perfor- mance after the fact. There was no correlation between math and spatial performance. A cultural stereotype can adversely affect performance in domains unrelated to the stereotype in question.

DISCUSSION

Who Is Most Likely To Fail Under Pressure In Math?

Establishing a link between WM and math failure not only provides insight into why poor performance occurs but also hints at important individual differences in susceptibility to failure. Although WM is often portrayed as a general cognitive construct, it is also an individual-difference variable—meaning some people have more of this general cognitive capacity than others. The more WM capacity individuals have, the better their performance on academic tasks like problem solving and reasoning (Engle, 2002). Thus, it is important to understand how those who come to the table with more or less of this WM resource are differently affected by the types of high-stakes situations in which math problem solving often occurs.

To explore this issue, Beilock and Carr (2005) asked indi- viduals lower (Lows) and higher (Highs) in WM to perform MA in a low-pressure and a high-pressure test (using the same pressure scenario as above). WM was assessed via measures that capture differences in one's general ability to maintain task-relevant information in the face of less-relevant or interfering information (Conway et al., 2005). Not surprisingly, Highs outperformed Lows under low-pressure conditions (Fig. 2). However, Highs' performance fell to the level of Lows' under pressure. Lows' performance did not suffer under pressure—even though they were performing well above chance to begin with (about 75% correct) and thus it was possible for them to get worse when the stakes were highest.

Why does pressure change the high-level performance of Highs while sparing Lows? To answer this, my colleague and I (Beilock & DeCaro, 2007) examined individuals' perceptions of pressure and their problem-solving strategies in low-pressure and high-pressure situations—again, using MA as a test bed.

Recall that MA involves judging math equations' truth value. Although one can do this by executing WM-demanding proce- dures, there are shortcuts that can be employed as well. For example, if one concludes that problems with even numbers are true because dividing two even numbers is associated less often with remainders than dividing two numbers of different parity, this will produce the correct answer on some trials [e.g., 34 Ξ 18 (mod 4)], but not always [e.g., 52 Ξ 16 (mod 8)]. This shortcut circumvents demands on WM, but it is not always correct.

If Highs are more likely to rely on demanding procedures (as opposed to shortcuts) precisely because they have the resources to successfully compute answers in this way—"if you've got it, flaunt it"—then this may be exactly what makes Highs sus- ceptible to failure (i.e., pressure may impact the WM supporting such demanding procedures). In contrast, if Lows rely on shortcuts because they do not have the resources to successfully execute demanding computations, pressure-induced consump- tion of WM should not disrupt performance.

Participants performed MA under low-pressure or high- pressure conditions and reported their problem-solving strate- gies and perceptions of pressure during math performance. cognitive tasks like math relate to stress-induced failure in other domains (e.g., sports skills)? Although outside the scope of this article, it turns out that compromises of WM are not the only mechanism by which high-stress situations exert their impact (see Beilock, Jellison, Rydell, McConnell, & Carr, 2006, for work in golf).

Addressing these questions will require converging behav- ioral and neuroscientific evidence that elucidates the brain structures and functions that individuals rely on to perform complex tasks in demanding environments. By understanding the cognitive and neural operations that contribute to skill success and failure, we will be better equipped to interpret performance in high-stakes situations and to devise training regimens and performance situations to ensure optimal perfor-mance—even when the pressure is on.

Under low pressure, Highs were more likely to use demanding subtraction and division steps (as opposed to simpler shortcuts) to solve MA, and they performed more accurately than Lows. Under high pressure, Highs used simpler (and less efficacious) shortcut strategies, and their performance suffered. Lows always relied on shortcuts and their performance was not affected by pressure. All individuals, regardless of WM, reported feeling similarly high levels of pressure during the high-pressure test (although see Gimmig, Huguet, Caverni, & Cury, 2006, who suggest that Lows and Highs may interpret high-stress situations differently).

CONCLUSION

Whether individuals are made aware of negative stereotypes about how they should perform or find themselves in a high- stakes situation in which there are monetary and social conse- quences associated with poor performance, stress-laden envi- ronments can negatively affect math performance. Moreover, this impact is not uniform across individuals. Ironically, those most likely to fail in demanding situations are those who, in the absence of pressure, have the greatest capacity for success.

These conclusions raise some interesting questions for future research. Is performance in low-stress situations a better pre- dictor of future academic and job success than traditional high- stakes tests? Why do stress-laden situations change how Highs approach demanding computations? And, are there procedures educators might adopt to reduce stress-induced math decre-ments? We have shown that practicing problems such that their solutions no longer require demanding computations alleviates stress effects (Beilock et al., 2004; 2007).

If careless mistakes on basic operations contribute to less-than-optimal performance, alleviating computational demands not only may prevent simple mistakes but also may free up WM resources for conceptual knowledge implementation—resources that are especially scarce under pressure. Finally, how do failures in complex.

REFERENCES

Gimmig, D., Huguet, P., Caverni, J.P., & Cury, F. (2006). Choking under pressure and working memory capacity: When performance pressure reduces fluid intelligence (Gf). *Psychonomic Bulletin & Review*, *13*, 1005–1010.

Hyde, J.S., Fennema, E., & Lamon, S.J. (1990). Gender differences in mathematics performance: A meta-analysis. *Psychological Bul- letin*, *107*, 139–155.

Imbo, I., Vandierendonck, A., & Verguewe, E. (2007). The role of working memory in carrying and borrowing. *Psychological Re- search*, *71*, 467–483.

Miyake, A., & Shah, P. (1999). *Models of working memory: Mechanisms of active maintenance and executive control*. New York: University Press.

Steele, C.M. (1997). A threat in the air: How stereotypes shape intellectual identity and performance. *American Psychologist*, *52*, 613–629.

Trbovich, P.L., & LeFevre, J. (2003). Phonological and visual working memory in mental addition. *Memory & Cognition*, *31*, 738–745.

Jon Bosak and Tim Bray. XML and the second-generation web. *Scientific American*, (5):243–247, May 1999.

Kim B. Bruce, Charles Kelemen, and Allen Tucker. Our curriculum has become math- phobic! In *SIGCSE Bulletin (ACM Special Interest Group on Computer Science Edu- cation)*, volume 33, pages 243–247, New York, NY, 2001. ACM Press.

Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, and Clifford Stein. *Intro- duction to Algorithms*. MIT Press/McGraw-Hill, New York, NY, second edition, 2001.

Computing curricula 2001: Computer science. *The Journal on Educational Resourcesin Computing*, 1(3es), Article No. 1, fall 2001.

George C. Necula. Proof-carrying code. In *Proceedings of the 24th ACM SIGPLAN- SIGACT symposium on Principles of programming languages*, pages 106–119, New York,NY, 1997. ACM Press.

The constants involved depend on the values of F and P. A very simple analysis is possible when the algorithm starts with an empty array and F = 1 (add 1 new element when the array runs out of space) and P = 100% (double the size of the array when it run out of space).

Ashcraft, M.H., & Kirk, E.P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General*, *130*, 224–237.

Beilock, S.L., & Carr, T.H. (2001). On the fragility of skilled perfor- mance: What governs choking under pressure? *Journal of Exper- imental Psychology: General*, *130*, 701–725.

Beilock, S.L., & Carr, T.H. (2005). When high-powered people fail: Working memory and ''choking under pressure'' in math. *Psy- chological Science*, *16*, 101–105.

Beilock, S.L., & DeCaro, M.S. (2007). From poor performance to success under stress: Working memory, strategy selection, and mathematical problem solving under pressure. *Journal of Exper- imental Psychology: Learning, Memory, & Cognition*, *33*, 983– 998.

Gimmig, D., Huguet, P., Caverni, J.P., & Cury, F. (2006). Choking under pressure and working memory capacity: When performance pressure reduces fluid intelligence (Gf). *Psychonomic Bulletin & Review*, *13*, 1005–1010.

Hyde, J.S., Fennema, E., & Lamon, S.J. (1990). Gender differences in mathematics performance: A meta-analysis. *Psychological Bul- letin*, *107*, 139–155.

Imbo, I., Vandierendonck, A., & Verguewe, E. (2007). The role of working memory in carrying and borrowing. *Psychological Re- search*, *71*, 467–483.

Miyake, A., & Shah, P. (1999). *Models of working memory: Mechanisms of active maintenance and executive control*. New York: University Press.

Steele, C.M. (1997). A threat in the air: How stereotypes shape intel- lectual identity and performance. *American Psychologist*, *52*, 613– 629.

Trbovich, P.L., & LeFevre, J. (2003). Phonological and visual working memory in mental addition. *Memory & Cognition*, *31*, 738–745.

Ashcraft, M.H., & Kirk, E.P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General*, *130*, 224–237.

Beilock, S.L., & Carr, T.H. (2001). On the fragility of skilled perfor- mance: What governs choking under pressure? *Journal of Exper- imental Psychology: General*, *130*, 701–725.

Beilock, S.L., & Carr, T.H. (2005). When high-powered people fail: Working memory and ''choking under pressure'' in math. *Psy- chological Science*, *16*, 101–105.

Beilock, S.L., & DeCaro, M.S. (2007). From poor performance to success under stress: Working memory, strategy selection, and mathematical problem solving under pressure. *Journal of Exper- imental Psychology: Learning, Memory, & Cognition*, *33*, 983– 998.

Ashcraft, M.H. (2002). Math anxiety: Personal, educational, and cog- nitive consequences. *Current Directions in Psychological Science*, *11*, 181–185. For readers who wish to learn more about math anxiety, this paper provides a fuller discussion of this phenome- non.

Beilock, S.L., & Carr, T.H. (2005). (See References). A representative study that illustrates original research on the relation between individual differences in cognitive capacity and performance under pressure.

Cadinu, M., Maass, A., Rosabianca, A., & Kiesner, J. (2005). Why do women underperform under stereotype threat? Evidence for the role of negative thinking. *Psychological Science*, *16*, 572–578. Discusses the role of situation-related worries in stereotype threat.

Schmader, T., & Johns, M. (2003). Converging evidence that stereotype threat reduces working memory capacity. *Journal of Personality and Social Psychology, 85*, 440–452. Discusses WM's involvement in the phenomenon of stereotype threat.

Gimmig, D., Huguet, P., Caverni, J.P., & Cury, F. (2006). Choking under pressure and working memory capacity: When performance pressure reduces fluid intelligence (Gf). *Psychonomic Bulletin & Review*, *13*, 1005–1010.

Hyde, J.S., Fennema, E., & Lamon, S.J. (1990). Gender differences in mathematics performance: A meta-analysis. *Psychological Bul- letin*, *107*, 139–155.

Imbo, I., Vandierendonck, A., & Verguewe, E. (2007). The role of working memory in carrying and borrowing. *Psychological Re- search*, *71*, 467–483.

Miyake, A., & Shah, P. (1999). *Models of working memory: Mechanisms of active maintenance and executive control*. New York: University Press.

Steele, C.M. (1997). A threat in the air: How stereotypes shape intellectual identity and performance. *American Psychologist*, *52*, 613–629.

Trbovich, P.L., & LeFevre, J. (2003). Phonological and visual working memory in mental addition. *Memory & Cognition*, *31*, 738–745.

Gimmig, D., Huguet, P., Caverni, J.P., & Cury, F. (2006). Choking under pressure and working memory capacity: When performance pressure reduces fluid intelligence (Gf). *Psychonomic Bulletin & Review*, *13*, 1005–1010.

Hyde, J.S., Fennema, E., & Lamon, S.J. (1990). Gender differences in mathematics performance: A meta-analysis. *Psychological Bul- letin*, *107*, 139–155.

Imbo, I., Vandierendonck, A., & Verguewe, E. (2007). The role of working memory in carrying and borrowing. *Psychological Re- search*, *71*, 467–483.

Miyake, A., & Shah, P. (1999). *Models of working memory: Mechanisms of active maintenance and executive control*. New York: University Press.

Steele, C.M. (1997). A threat in the air: How stereotypes shape intellectual identity and performance. *American Psychologist*, *52*, 613–629.

Trbovich, P.L., & LeFevre, J. (2003). Phonological and visual working memory in mental addition. *Memory & Cognition*, *31*, 738–745.