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Why do high working memory individuals choke? An examination of choking under pressure effects in math from a self-improvement perspective☆

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ABSTRACT

Choking under pressure (CUP) research shows that individuals working on higher-order cognitive tasks do not benefit from higher working memory (WM) capacity under pressure. This CUP effect, or reduced WM/performance link, entails that high working memory individuals (high WMs) perform at about the same level as low WMs. However, it still is an open question which specific components create a high pressure situation. We hypothesized that CUP effects should occur in situations where high WMs are faced with a self-improvement goal, particularly when they do not have much room to improve their performance any further. Study 1 demonstrated that the positive WM/math performance link was reduced in the mere presence of a self-improvement goal. Study 2 further showed that the WM/math performance link was only reduced when self-improvement instructions emphasized that there was not much room left for improvement. Discussion focuses on implications for both CUP and achievement goal research.

1. Introduction

Working Memory (WM) is an executive resource used to perform higher-order cognitive tasks, which can be conceived of, in line with Baddeley and Hitch's (1974) framework, as a "limited-resource system with storage and processing capabilities" (Kane, Conway, Hambrick, & Engle, 2007, p. 21). WM is positively related to fluid intelligence (Unsworth & Engle, 2005), mathematical problem solving (see Ashcraft & Kirk, 2001; Raghubar, Barnes, & Hecht, 2010, for reviews; see also Uittenhove & Lemaire, 2013), and academic achievement more generally (Alloway & Alloway, 2010). Consequently, the positive WM/performance link should be quite robust for higher-order cognitive tasks, as such tasks require rule and goal maintenance for successful completion, which are mental operations at which high WM individuals are better than their low WM counterparts. The former will therefore usually perform better than the latter on tasks such as matrix reasoning if fluid intelligence is assessed (e.g., Unsworth & Engle, 2005), or number operations if mathematical competence is of interest (e.g., Alloway & Alloway, 2010; Bull & Scerif, 2001).

However, choking under pressure research (CUP; Beilock, Kulp, Holt, & Carr, 2004) shows that in high-pressure situations, individuals working on higher-order cognitive tasks do not benefit from higher WM capacity, leading high WMs to perform at about the same level as their low WM counterparts and resulting in a reduced WM/performance link (Beilock & Carr, 2005). Phrased differently, in high-pressure situations, a reduced WM/performance link indicates that high WM individuals choke under pressure. A similar, high WMs-specific effect of testing situations has also been observed using a dual-task paradigm: Adding a secondary task (i.e., making the task more complex) hampered high WMs' performance while that of low WMs was unaffected (Kane & Engle, 2000; Rosen & Engle, 1997). Together, these findings suggest that situational features have the potential to prevent high WMs from using all of their available cognitive resources. This explains why their performance suffers (i.e., why they choke under pressure), but not that of low WMs who use less complex solving strategies to begin with (hence reducing the influence of contextual factors on performance).

Although the cognitive mechanisms behind CUP start to be rather well understood (e.g., Beilock & DeCaro, 2007; Beilock et al., 2004; DeCaro, Thomas, Albert, & Beilock, 2011), it remains less clear which specific components create a high pressure situation, and accordingly,

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affect performance on higher-order cognitive tasks. Indeed, pressure has typically been induced through a combination of elements: (i) a self-improvement goal, (ii) a performance-contingent monetary reward coupled with team effort, and (iii) being videotaped (Beilock & Carr, 2005; Beilock & DeCaro, 2007; Beilock et al., 2004). Recent findings suggest that being videotaped may be the pressure component that harms performance on tasks that do not require WM for successful execution (DeCaro et al., 2011), but no research has investigated whether one of the other two components may be specifically involved in CUP effects on tasks that do require WM for successful completion. Because we suspected the self-improvement goal to be the key factor, particularly when there is not much room left for self-improvement, the aim of the present research was to examine whether this particular goal may have different consequences for high and low WMs.

Indeed, there is a logical principle stating that the lower one's initial performance level, the more room there is for further improvement and vice versa (Critcher & Rosenzweig, in press). That is, when working on a task, low performers have the latitude to improve their level of task mastery and performance, whereas similar improvements by high performers will be more difficult to achieve given their high performance level. Arguably, the less room for improvement, the more pressure is put on the individual when pursuing a self-improvement goal. Hence, on higher-order cognitive tasks – tasks on which high-WMs have an advantage under standard instructions – under self-improvement instructions, high WMs will have only limited room for improvement, resulting in higher pressure and suboptimal performance. Conversely, low WMs will have more room for improvement, resulting in less pressure. If high WMs' performance is reduced and that of low WMs remains stable, the WM/performance link is also reduced, which indicates a CUP effect.

In addition, research in the area of achievement goals has shown that self-improvement goals – hereafter referred to as a mastery goals[1] – lead to better performance than other achievement goals (i.e., performance goals or avoidance goals) or no goal (for a recent meta-analysis, see Van Yperen, Blaga, & Postmes, 2015; see also Dompnier, Darnon, & Butera, 2009; Hulleman, Schrager, Bodmann, & Harackiewicz, 2010; Poortvliet & Darnon, 2010; Senko, Hulleman, & Harackiewicz, 2011; Van Yperen, Blaga, & Postmes, 2014). However, there are situations where this is not the case, for example, when there are external pressures or constraints such as the anticipation of external feedback on one's task performance or a strict time limit to perform the task (Van Yperen et al., 2015). Similarly, Avery, Smillie, and de Fockert (2013) showed that under secondary task load, mastery goal participants suffered a more severe performance decrement on the primary task than performance goal participants. This is because the former used more complex and WM intensive solving strategies, which undermined performance when load increased. Other research suggests that mastery goals hinder performance improvement in instances of success feedback (i.e., your score on this task is 95% correct; Cianci, Schaubroeck, & McGill, 2010), and that because low achievers have more to learn than high achievers, the former, but not the latter, benefit from mastery goals (Butler, 1993). Also, whereas mastery goals foster inter-individual cooperation when there is room for performance improvement (i.e., for low-ranked individuals), this is not so when there is hardly any room for improvement (i.e., for high-ranked individuals; Poortvliet, Janssen, Van Yperen, & Van de Vliert, 2009). Past research thus suggests that some of the typical benefits associated with mastery goals (i.e., cooperation and learning) are jeopardized when mastery goal individuals do not have much room for improvement.

Following this line of reasoning, CUP effects should occur in situations where high WMs working on a higher-order cognitive task are faced with a mastery goal. That is, the WM/performance link should be reduced due to high WMs' reduced performance levels whereas low WMs – who have more room for improvement – were expected to maintain their performance levels. In Study 1, we tested this hypothesis in two phases. In the first phase, we did not implement other components of the pressure scenario (i.e., reward and team effort, being videotaped). This allowed testing for the sheer effect of mastery goals without the possible confounding effect of the other pressure-inducing components. Specifically, in the first phase, we compared the effects of a situationally induced mastery goal with two control conditions: (Kane & Engle, 2000) a performance goal control condition to test whether the effect can be explained by a mastery goal rather than another type of achievement goal, and (Murayama & Elliot, 2011) a no-goal control condition. Our mastery goal manipulation closely paralleled Beilock and Carr's (2005) self-improvement goal manipulation. That is, we recommended participants to improve their performance relative to the preceding trials. In the performance goal control condition, we recommended the participants to adopt a performance-approach goal (henceforth referred to as a performance goal), that is, the goal to perform better than the other participants (Crouzevialle & Butera, 2013; Elliot, 2005). In the no goal control condition, no achievement goal was induced. This control condition plays a crucial role as it provides an anchor of what would be the typical WM/math performance link (i.e., how low and high WMs typically perform) in the absence of any goal. Hereafter, we will refer to this first phase as to the goal only scenario.

In the second phase, hereafter labeled CUP scenario, we also distinguished between a mastery goal, a performance goal control condition, and a no goal control condition, but we added all the situational components typically used in CUP research (see above). This resulted in a mastery goal condition similar to the high pressure condition in the Beilock and Carr (2005) study, and a performance goal control condition, which only differed from the high pressure condition in the Beilock and Carr (2005) study in terms of goal type. The no goal control condition was the same as in the first phase.

This two-phase design allowed testing whether high WMs' CUP occurs – and the WM/performance link is reduced – in the mastery goal condition of both goal only and CUP scenarios, that is, in the mere presence of the self-improvement requirement. In contrast, in either control condition, we expected to observe the typical positive WM/performance link. Thus, in Study 1, we tested whether a mastery goal, but no other situational components or another type of achievement goal, specifically accounted for the reduced WM/performance link.

In Study 2, we manipulated mastery goal individuals' room for improvement in order to test the mechanism hypothesized to account for high WMs' CUP (Spencer, Zanna, & Fong, 2005). More precisely, in two CUP scenario experimental conditions, we tested whether a mastery goal would lead to a reduced WM/performance link when participants are explicitly informed that they do not have much room for improvement, but not when informed that they do have substantial room for improvement. Also, in an additional no goal control condition, we expected to observe the typical WM/math performance link.

2. Study 1

2.1. Method

2.1.1. Participants and design

Participants (tested individually) were 139 female French undergraduate students from various academic disciplines ($M_{Age} = 21$ years, $SD = 2.71$). Data from one participant were removed because the computer failed to record her WM score and from another because of both an uncommon studentized deleted residual and an extreme Cook's distance value (Judd & McClelland, 1989). It is important to emphasize that extreme values on studentized deleted residuals and Cook's distances are problematic in regression analysis because they have the potential to drastically increase residuals or bias parameter estimates, and therefore to increase the model's error. In accordance with Judd

[1] Precisely, we are referring to a mastery-approach goal, as it is the approach component that has been emphasized in typical pressure scenarios.

and McClelland (1989), excluding these extreme values is therefore mandatory if the regression results are meant to fit most observations, and not a few extreme values.

Participants were randomly assigned to one of the three between-subjects conditions (44, 47, and 46 in the mastery goal, performance goal control, and no goal control conditions, respectively). They all completed test set 1 math problems with the goal only scenario (phase 1) and test set 2 math problems with the CUP scenario (except for the no goal control condition). WM was a continuous variable (see Cohen, 1983, for the costs associated with dichotomizing a continuous variable).

2.1.2. Materials and procedure

After signing a consent form, participants completed the same modular arithmetic (MA) problems as in Beilock and Carr (2005). These math problems consist in judging the validity of statements such as 42 ≡ 15 (mod 4). To solve the problems, participants have to mentally subtract the middle number from the first number (42 − 15) and to divide the difference by the last number (27 / 4). If the result is a whole number, the statement is true; otherwise, it is false. In addition, the two operands may or may be large numbers (>20, according to Beilock & Carr, 2005). As a consequence, the MA problems may have two large-number operands (e.g., 45 ≡ 27), one large-number operand (e.g., 42 ≡ 15), or no large-number operands (e.g., 9 ≡ 3). Depending on the presence of large numbers (and subsequent borrow operations), MA problems place different demands on WM (Beilock & Carr, 2005). This allows classifying the MA problems as a function of their WM demands.

Following Beilock et al.'s (2004) distinction, in their seminal work, between low, intermediate, and high demand problems, we classified MA problems in the present research in one of the three following categories: 1) low-demand problems if there were no large number operands; 2) intermediate-demand problems if there was one large-number operand; 3) high-demand problems if there were two large-number problems. Choking effects generally occur on problems that place higher demands on WM (i.e., intermediate and high-demand problems; Beilock & Carr, 2005; Beilock et al., 2004; Gimmig, Huguet, Caverni, & Cury, 2006). Throughout the trials, participants were instructed to judge the problems as quickly and as accurately as possible by pressing one of two key presses, and were given feedback after each trial (no additional feedback was provided after each set). Furthermore, in the instruction, both speed and accuracy were emphasized so that participants could not assess their own performance (Beilock & Carr, 2005; Beilock et al., 2004).

All participants performed 6 practice problems (2 low-demand, 2 moderate-demand, 2 high-demand), 24 set 1 (12 low-demand, 8 intermediate-demand, and 4 high-demand) and 24 set 2 problems (12 low-demand, 10 intermediate-demand, and 2 high-demand). In the no-goal control condition, instructions for both set 1 and set 2 only asked participants to do their best. This control condition served as a baseline for the WM/performance link in the absence of goal activation. In the mastery goal condition, participants were recommended to improve their score on the practice items by 20% (as in Beilock & Carr, 2005; see also Van Yperen, 2003). In the performance goal condition, participants were instructed to perform better than the average score of the other participants. To equate goal conditions for perceptions of goal difficulty, participants were told that to attain their mastery [performance] goal, they should get a score of 15 (Van Yperen, 2003; see also Senko & Harackiewicz, 2005, for the importance of equating difficulty level of mastery and performance goals). In the mastery goal condition, there was no reason for the participants to be suspicious about this target score because their level of performance on the practice trials was determined by both speed and accuracy, which makes it virtually impossible for them to precisely infer their own performance.

In set 2, the CUP scenario was implemented (Beilock & Carr, 2005). Specifically, in the mastery goal condition, the scenario stated that a) if the participant improved her score on the practice items by 20%, she would get a 5 euro bonus (10 euros were already warranted in exchange for participation); b) she had been paired with another participant who had already improved by 20%, and that both the participant and her partner had to improve to get the bonus; and c) she would be videotaped so that local math teachers could analyze her performance (the experimenter set up the camera at this point and instructions were rehearsed aloud). In the performance goal condition, participants were – as for set 1 – asked to perform better than others and, in addition, received the following pressure scenario: a) if the participant performed better than the average score of the others, she would get a 5 euro bonus (10 euros were already warranted in exchange for participation); b) she had been paired with another participant who had already performed better than the average score of the others, and that both the participant and her partner had to outperform the others to get the bonus; and c) she would be videotaped so that local math teachers could analyze her performance (the experimenter set up the camera at this point and instructions were rehearsed aloud).

Thus, for set 2, the mastery goal condition was equivalent to Beilock and Carr's (2005) CUP scenario, while the performance goal condition only differed in terms of goal activation. Upon completion of set 2, participants provided demographic information. They were then informed that the experiment was finished, but were invited to participate in an unrelated study on memorization (which corresponded to the WM task). All participants agreed to do so. As in Beilock and Carr (2005), to allow pressure to fall down, participants were invited to relax during a short break and were then instructed to complete the WM task (accordingly, there was no effect of condition on WM, $p = .95$).

The WM task was introduced as a series of memory exercises and the reading span (Daneman & Carpenter, 1980) was used to avoid similarities with the math task. An automated reading span in French (Desmette, Hupet, Schelstraete, & van der Linden, 1995; Unsworth, Heitz, Schrock, & Engle, 2005) was developed ($M_{Study\ 1} = 41.36$, $SD = 16.70$ and $M_{Study\ 2} = 35.86$, $SD = 16.28$; see Redick et al., 2012, for normative data in the United States). In this task, participants process the meaning of sentences (i.e., decide whether a sentence makes sense or not) while trying to remember unrelated letters. After each sentence–letter series, participants have to recall the letters they have seen in the correct order. There were 15 series, with each series' length ranging from 3 to 7 (see Unsworth et al., 2005). WM scores were equal to the sum of all perfectly recalled series. Finally, participants were thanked, paid 15 euros regardless of performance, and fully debriefed.

2.2. Results

2.2.1. Performance on set 1 MA problems (goal only scenario)

Accuracy scores for low, intermediate, and high-demand MA problems represented our main performance indicators (as in Beilock et al., 2004, we first removed trials with RTs more than 3 standard deviations below or above an individual's mean RT). Descriptive statistics are reported in Table 1.

Accuracy scores on low, intermediate, and high-demand problems were separately regressed on WM (mean-centered), two orthogonal

Table 1
Descriptive statistics for Study 1 measures.

Measures	Mean	Standard deviations
Set 1		
Low-demand problems accuracy scores	.94	.10
Intermediate-demand problems accuracy scores	.85	.15
High-demand problems accuracy scores	.73	.23
Set 2		
Low-demand problems accuracy scores	.94	.10
Intermediate-demand problems accuracy scores	.70	.18
High-demand problems accuracy scores	.84	.26

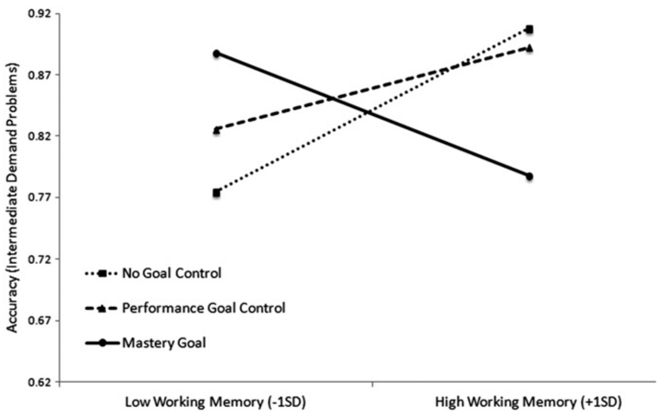

Fig. 1. Study 1 goal only scenario (set 1): Modular arithmetic accuracy scores on intermediate demand problems as a function of condition and working memory.

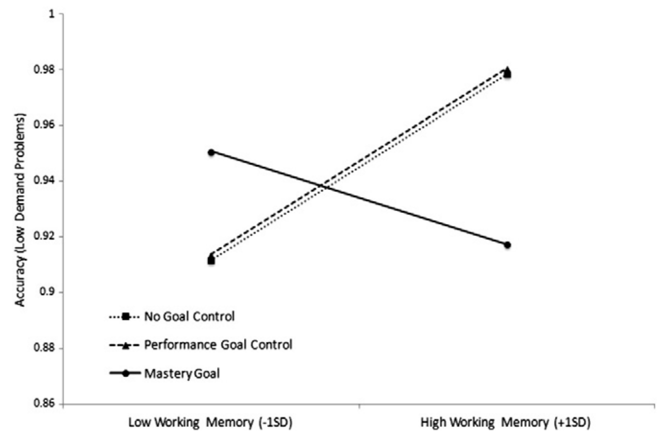

Fig. 2. Study 1 goal only scenario (set 1): Modular arithmetic accuracy scores on low demand problems as a function of condition and working memory.

contrasts – C1 (no goal control: −1, mastery goal: 2, performance goal control: −1) and C2 (no goal control: −1, mastery goal: 0, performance goal control: 1) – and their interactions. Indeed, as we a priori predicted that the WM/performance link should be reduced in the mastery goal condition as compared to either control condition, the use of two orthogonal contrasts was relevant. The first contrast (C1), which opposed the mastery goal condition to the other conditions, in interaction with WM, tested our central prediction. The second contrast (C2), alone or in interaction with WM, was theoretically irrelevant and was expected to be non-significant.

The C1 × WM interaction – which tested our central hypothesis – was significant for low-demand problems, $\beta = -0.18$, $t(131) = -2.13$, $p < .04$, $\eta_p^2 = .03$, and intermediate-demand problems, $\beta = -0.23$, $t(131) = -2.76$, $p < .01$, $\eta_p^2 = .06$, but not for high-demand problems, $\beta = -0.10$, $t(131) = -1.13$, $p > .26$. More precisely, the WM/performance relation was reduced in the mastery goal condition as compared to the control and performance goal conditions, for both the low and intermediate-demand problems (Figs. 1 and 2). No other main or interaction effects were significant.[2] The same analyses were performed on reaction times for correct problems, which revealed, for low-demand problems only, a main effect of WM, $\beta = -0.21$, $t(131) = -2.49$, $p < .05$, ${\eta_p}^2 = .05$, and of C1, $\beta = 0.18$, $t(131) = 2.19$, $p < .05$, ${\eta_p}^2 = .04$.

2.2.2. Performance on set 2 MA problems (CUP scenario)

To test for these links when the CUP scenario was implemented, low, intermediate, and high-demand problems set 2 accuracy scores were separately regressed on the same model as set 1 scores. Results revealed a main effect of WM on the high-demand problems only, $\beta = 0.24$, $t(131) = 2.87$, $p < .01$, ${\eta_p}^2 = .06$, and the expected C1 × WM interaction effect on the intermediate-demand problems only, $\beta = -0.18$, $t(131) = -2.12$, $p < .04$, ${\eta_p}^2 = .03$ ($\beta = 0.08$, $t(131) = 0.96$, $p > .34$ for high-demand problems, and $\beta = -0.13$, $t(131) = -1.45$, $p > .14$ for low-demand problems). Consistent with set 1 findings, as compared to the control and performance goal conditions, the WM/performance link was reduced in the mastery goal condition (see Fig. 3). Thus, findings for set 2 problems closely paralleled those observed for set 1.

Analyses on reaction times for correct problems showed a main negative effect of WM on low-demand, $\beta = -0.20$, $t(131) = -2.35$, $p < .05$, ${\eta_p}^2 = .04$, intermediate-demand, $\beta = -0.17$, $t(131) = -1.98$, $p = .05$, ${\eta_p}^2 = .03$, and high-demand problems, $\beta = -0.17$, $t(131) = -1.92$, $p = .03$, ${\eta_p}^2 = .03$. Additionally, a main effect of C1 was found, $\beta = 0.18$, $t(131) = 2.08$, $p < .05$, ${\eta_p}^2 = .03$. Because these main effects were not of theoretical importance here, and as no interaction effects were involved, results regarding reaction times were not discussed further.

2.2.3. Effects of test set

Finally, to test for the within-subjects effect of test set, set 1/set 2 difference scores were computed for low, intermediate, and high-demand problems, and separately regressed on C1, C2, WM, and their interactions (Judd, McClelland, & Ryan, 2009). With this method, the within-subjects effect of test set is tested with the significance test for the intercept. Results indicate that, for low-demand problems, no effect of test set was found, $t(131) = -.35$, $p > .72$. For intermediate-demand problems, an effect of test set was found, $t(131) = 9.41$, $p < .01$, with better performance on set 1 ($M = .85$, $SD = .15$) than on set 2 problems ($M = .70$, $SD = .18$). For high-demand problems instead, a better performance was observed on set 2 problems ($M = .84$, $SD = .26$) than on set 1 problems ($M = .73$, $SD = .23$), $t(131) = -4.04$, $p < .01$. No other main or interaction effects were found, indicating that test set effects were observed regardless of condition, including the no goal control condition where no pressure scenario was introduced.

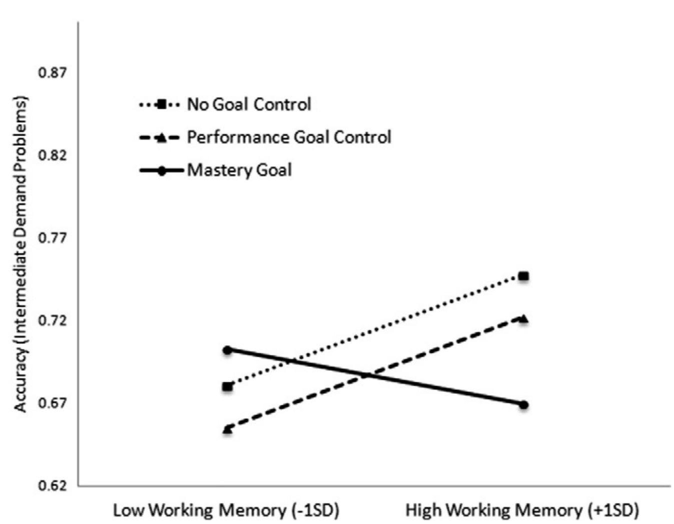

Fig. 3. Study 1 choking under pressure scenario (set 2): Modular arithmetic accuracy scores on intermediate demand problems as a function of condition and working memory.

[2] We also created an aggregate accuracy score for the intermediate and high-demand problems for phases 1 and 2. These scores were regressed on the same model and findings were virtually unchanged. For phase 1, only the C1 × WM interaction was significant, $\beta = -0.23$, $t(131) = -2.69$, $p < .01$, ${\eta_p}^2 = .05$, and in the same direction as in the main analyses. For phase 2, both the main effect of WM, $\beta = 0.17$, $t(131) = 1.98$, $p < .05$, ${\eta_p}^2 = .03$, and the C1 × WM interaction effect were significant, $\beta = -0.16$, $t(131) = -1.94$, $p = .05$, ${\eta_p}^2 = .03$.

2.3. Discussion

As expected, our findings demonstrate that the positive WM/performance relationship observed in the performance goal and no goal control conditions was reduced in the mastery goal conditions. That is, pursuing a mastery or self-improvement goal is problematic particularly for high WMs and causes their sub-optimal performance. Importantly, this pattern was found in the mastery goal condition of both goal only and CUP scenarios, indicating that additional pressure-inducing elements (i.e., performance-contingent monetary reward, team effort, videotape) had no additional influence in high WM's CUP. The only noticeable difference between set 1 and set 2 findings was the unexpected result that the WM/performance link in the mastery goal condition was also reduced for set 1 low-demand problems, and not only for intermediate-demand problems. Finally, we did not find a WM by condition effect on the high-demand problems (on either set 1 or set 2). We will return to these points in the General Discussion.

Although these findings support our general hypothesis that the self-improvement component of mastery goals is problematic for high WMs and hence accounts for CUP effects, some limitations should be noticed. First, as our aim was to examine CUP effects and the reduced WM/performance link in math from a situational perspective, we remained as close as possible to typical CUP instructions (Beilock & Carr, 2005; Beilock et al., 2004). Consequently, we did not explicitly manipulate how much room for improvement participants had, thereby limiting the possibility to provide direct evidence that it was the lack of room for improvement that was detrimental for high WMs' performance under self-improvement instructions. Having established the specific consequences of a mastery goal for the WM/math performance link with the use of typical CUP instructions, we conducted a second study where self-improvement instructions were maintained constant and we directly manipulated participants' room for improvement through (bogus) performance feedback.

Second, only female participants were recruited in Study 1. This was done given that, in previous CUP studies, percentage of female and male participants were seldom reported, leaving the possibility that CUP effects in math were driven by men's responses alone, while women's performance may have been affected by stereotype threat (Spencer, Steele, & Quinn, 1999). As we found CUP effects in our all-female sample in Study 1, this alternative explanation is unlikely and, consequently, both female and male participants were recruited in Study 2.

Third, although the reduced WM/performance relation in the mastery goal condition was observed for set 1 and set 2 intermediate-demand MA problems, this was also the case for set 1 low-demand problems, which was unexpected given previous CUP research. Because we could not determine whether this effect was driven by the content of set 1 MA problems or by the absence of the CUP scenario, we reused these same set 1 problems in Study 2 while maintaining the CUP scenario constant. In other words, in Study 2, both the room-for-improvement and the critical no-room-for-improvement conditions were implemented along with the CUP scenario.

3. Study 2

The primary aim of Study 2 was to manipulate the mechanism hypothesized to account for the reduced WM/performance link under self-improvement instructions: Reduced room for improvement. To do so, we modified Study 1's mastery goal/CUP scenario so as to provide bogus feedback on participants' performance. We further distinguished between a room-for-improvement condition, where both low and high WMs were expected to perform at their habitual level (i.e., positive WM/performance relation), and a no-room-for-improvement condition, where high WMs were expected to choke and the WM/performance relation should be reduced. As in Study 1, we also included a no goal control condition.

3.1. Method

3.1.1. Participants and design

Participants (tested individually) were 95 French psychology undergraduates ($M_{Age} = 20$ years, SD = 1.71). Data from one participant were removed because the computer failed to record her MA performance and those from 3 others because they displayed both an uncommon studentized deleted residual and an extreme Cook's distance value (2 in the control condition and 1 in the no-room-for-improvement/95% condition), leaving a final sample of 91 participants (77 female). Participants were randomly assigned to one of three experimental conditions (32, 33, and 26 in the no-room-for-improvement/95%, room-for-improvement/20%, and control conditions, respectively). WM was a continuous variable.

3.1.2. Materials and procedure

The procedure closely paralleled that from Study 1's set 2. After signing a consent form, all participants first performed the same 6 practice MA problems. In the control condition, participants were subsequently instructed to do their best on the upcoming trials (as in Study 1). In the two other conditions, as in the mastery goal condition of Study 1, participants were recommended to self-improve. In the room-for-improvement condition [no-room-for-improvement condition], instructions stated that the computer had calculated that participants' mastery level of the task was 20% [95%] and that they had to improve this level. They then received the same CUP instructions as in Study 1 (except from the target goal of 15, which was removed as type of goal remained constant). Thus, after receiving the level of task mastery feedback, participants were informed that they would get a 5 euros bonus if they improved this level, that they had been paired with another participant, that both the participant and her partner had to improve to get the bonus, and that they would be videotaped so that local math teachers could analyze their performance (the experimenter set up the camera as in Study 1). Following instructions, all participants completed the same 24 set 1 MA problems from Study 1 (12 low-demand, 8 moderate-demand, 4 high-demand). Upon completion of the MA problems, they reported demographic information, were invited to take a short break and to participate in an unrelated study on memorization (i.e., the automated reading span; no effect of condition on span score, $p = .77$). They were subsequently debriefed, thanked, and paid.

3.2. Results

Accuracy scores on the low, intermediate, and high-demand MA problems represented our main performance indicators (as in Study 1, trials with RTs more than 3 standard deviations below or above an individual's mean RT were removed). Descriptive statistics are reported in Table 2.

The same regression model as in Study1 was used to examine the WM/performance link in the three conditions: in three separate analyses, we regressed low, intermediate, and high-demand problems accuracy scores on WM (mean-centered), two orthogonal contrasts – C1 (no goal control: −1, no-room-for-improvement: 2, room-for-improvement: −1) and C2 (no goal control: −1, no-room-for-improvement: 0, room-for-improvement: 1) – and their interactions. Only the C1 × WM interaction – which again tested our central

Table 2
Descriptive statistics for Study 2 measures.

Measures	Mean	Standard deviations
Low-demand problems accuracy scores	.95	.09
Intermediate-demand problems accuracy scores	.83	.13
High-demand problems accuracy scores	.72	.21

hypothesis – was significant for the intermediate problems, $\beta = -0.24$, $t(85) = -2.32$, $p < .03$, $\eta_p^2 = .06$, and indicated that the WM/performance link was reduced in the no-room-for-improvement condition as compared to the control and room-for-improvement conditions (Fig. 4). No other main or interaction effects were significant for any of the other performance indicators. Analyses on reaction times only showed a main effect of WM on the low-demand problems and are not discussed further.

3.3. Discussion

By manipulating the mechanism hypothesized to account for the reduced WM/performance link under self-improvement instructions, results from Study 2 demonstrated that, when the mastery goal was held constant, this link was reduced in the no-room-for-improvement condition as compared to the room-for-improvement and control conditions. Therefore, these findings provide direct evidence that it is indeed the lack of room for improvement that hampers high WMs' performance under self-improvement instructions, as the room-for-improvement and the no-room-for-improvement conditions only differed in terms of how much room for improvement participants had. In addition, results confirmed that the reduced WM/performance link was observed on intermediate-demand problems, but not on low and high-demand problems. Thus, the unexpected findings obtained on Study 1 — set 1 low-demand MA problems were not observed in Study 2.

4. General discussion

While CUP effects are well established, Beilock et al. (2004) acknowledge that how the different pressure-inducing elements exert their influence on cognitive performance remains an empirical question. Relying on achievement goal research, we argued that, specifically, the mastery – or self-improvement – goal typical of pressure instructions should be problematic for high WMs and cause their sub-optimal performance. Consistent with this hypothesis, we demonstrated in Study 1 that the positive WM/performance relationship observed in the performance goal and no goal control conditions for intermediate-demand MA problems was reduced in the mastery goal condition, that is, in a situation where self-improvement instructions were provided. Importantly, this pattern was observed in the mastery goal condition with both the goal only and the CUP scenario. Our findings therefore suggest that it is the mastery goal, but not other situational components (i.e., reward, team effort, videotape) or another goal (performance goal) that accounted for high WM's CUP.

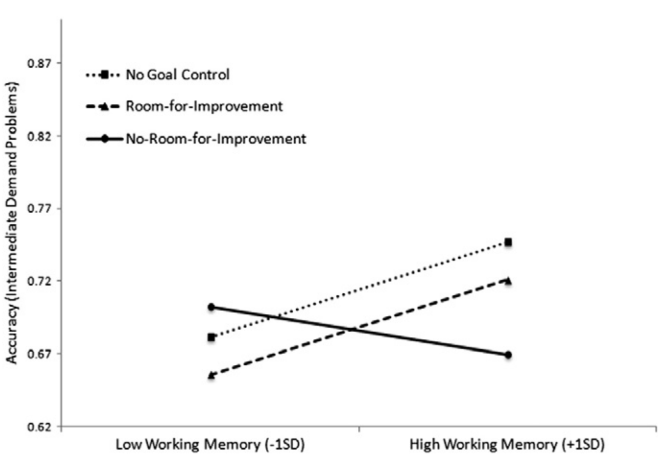

Fig. 4. Study 2 choking under pressure scenario: Modular arithmetic accuracy scores on intermediate demand problems as a function of condition and working memory.

Refining Study 1 results and the role of self-improvement, Study 2 findings provided direct support for the lack of room for improvement hypothesis, as they showed that when self-improvement instructions were held constant, the WM/math performance link was reduced in the no-room-for-improvement condition (task mastery of 95%) as compared to the room-for-improvement (task mastery of 20%) and control conditions. Furthermore, across studies, results consistently demonstrated a positive WM/performance relation in the control conditions, signaling that in the absence of mastery goal manipulation, high WMs typically perform better than low WMs, which is in accordance with high WMs' advantage in many performance domains. Together, findings from two studies thus provide convergent evidence for the determining role of a self-improvement requirement in high WMs' CUP and for the hypothesized underlying mechanism, namely, a lack of room for improvement. As such, the present research represents the first attempt to disentangle the relative influence of choking scenario components on tasks that require WM for successful completion and to provide a direct test of the hypothesized underlying mechanism.

A less expected, though consistent finding was that the reduced WM/math performance relation was never observed on high-demand problems. This may seem inconsistent with past choking research, where similar MA problems were used. However, although Beilock and colleagues (Beilock et al., 2004) initially distinguished between low, intermediate, and high-demand problems, they did not analyze CUP effects on intermediate-demand problems and, additionally, used a different categorization criterion. In their subsequent research (e.g., Beilock & Carr, 2005; Ramirez & Beilock, 2011), they only distinguished between low and high-demand problems. As the present series of findings suggest, a more fine-grained categorization provides new insights as to which problems are primarily involved in choking effects. However, given the small number of high-demand problems here – which may have limited response variability and/or reliability – future CUP research may include a larger number of high-demand problems, which should help clarifying the effects of choking on this type of problems.

In addition to their implications for CUP research, the present research also contributes to the achievement goal literature by demonstrating that the link between goal type (manipulated) and performance may depend on individual differences in WM. Indeed, while mastery goals seem to be well adapted to low WMs (and possibly, by extension, to low achievers and novices), performance goals appear more suitable for high WMs (and, possibly, for high achievers and experts). Such an implication may be related to more prototypical goal research which has shown that mastery goals are particularly beneficial for low achievers as compared to high achievers (Butler, 1993; Gabriele & Montecinos, 2001) and for low-status as compared to high-status students, whereas performance goals are better adapted to the latter than to the former (Smeding, Darnon, Souchal, Toczek-Capelle, & Butera, 2013).

In conclusion, the present findings add to a growing body of literature suggesting that the benefits and drawbacks of achievement goal pursuit could be more fully understood by taking into account who is pursuing them, which context is at stake (e.g., Darnon, Dompnier, & Poortvliet, 2012; Poortvliet, 2013; Poortvliet et al., 2009), which performance criteria are under investigation (e.g., Murayama & Elliot, 2011), and/or which performance criteria people actually use (Van Yperen & Leander, 2014).

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References

Alloway, T.P., & Alloway, R.G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, *106*, 20–29. http://dx.doi.org/10.1016/j.jecp.2009.11.003.

Ashcraft, M.H., & Kirk, E.P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General*, *130*, 224–237. http://dx.doi.org/10.1037/0096-3445.130.2.224.

Avery, R.E., Smillie, L.D., & de Fockert, J.W. (2013). The role of working memory in achievement goal pursuit. *Acta Psychologica*, *144*, 361–372. http://dx.doi.org/10.1016/j.actpsy.2013.07.012.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory. Vol. 8*. (pp. 47–89). New York: Academic Press.

Beilock, S.L., & Carr, T.H. (2005). When high-powered people fail: Working memory and 'choking under pressure' in math. *Psychological Science*, *16*, 101–105. http://dx.doi.org/10.1111/j.0956-7976.2005.00789.x.

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 Experimental Psychology: Learning, Memory, and Cognition*, *33*, 983–998. http://dx.doi.org/10.1037/0278-7393.33.6.983.

Beilock, S.L., Kulp, C.A., Holt, L.E., & Carr, T.H. (2004). More on the fragility of performance: Choking under pressure in mathematical problem solving. *Journal of Experimental Psychology: General*, *133*, 584–600. http://dx.doi.org/10.1037/0096-3445.133.4.584.

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Shifting, inhibition, and working memory. *Developmental Neuropsychology*, *19*, 273–293. http://dx.doi.org/10.1207/S15326942DN1903_3.

Butler, R. (1993). Effects of task- and ego-achievement goals on information seeking during task engagement. *Journal of Personality and Social Psychology*, *65*, 18–31. http://dx.doi.org/10.1037/0022-3514.65.1.18.

Cianci, A.M., Schaubroeck, J.M., & McGill, G.A. (2010). Achievement goals, feedback, and task performance. *Human Performance*, *23*, 131–154. http://dx.doi.org/10.1080/08959281003621687.

Cohen, J. (1983). The cost of dichotomization. *Applied Psychological Measurement*, *7*, 249–253. http://dx.doi.org/10.1177/014662168300700301.

Critcher, C.R., & Rosenzweig, E.L. (2014s). The performance heuristic: A misguided reliance on past success when predicting prospects for improvement. *Journal of Experimental Psychology: General*. http://dx.doi.org/10.1037/a0034129 (In press).

Crouzevialle, M., & Butera, F. (2013). Performance-approach goals deplete working memory and impair cognitive performance. *Journal of Experimental Psychology: General*, *142*, 666–678. http://dx.doi.org/10.1037/a0029632.

Daneman, M., & Carpenter, P.A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *19*, 450–466. http://dx.doi.org/10.1016/S0022-5371(80)90312-6.

Darnon, C., Dompnier, B., & Poortvliet, P.M. (2012). Achievement goals in educational contexts: A social psychology perspective. *Social and Personality Psychology Compass*, *6*, 760–771. http://dx.doi.org/10.1111/j.1751-9004.2012.00457.x.

DeCaro, M.S., Thomas, R.D., Albert, N.B., & Beilock, S.L. (2011). Choking under pressure: Multiple routes to skill failure. *Journal of Experimental Psychology: General*, *140*, 390–406. http://dx.doi.org/10.1037/a0023466.

Desmette, D., Hupet, M., Schelstraete, M. -A., & van der Linden, M. (1995). Adaptation en langue française du 'Reading Span Test' de Daneman et Carpenter (1980) [A French version of M. Daneman and P. A. Carpenter's (1980) Reading Span Test (RST)]. *L'Année Psychologique*, *95*, 459–482.

Dompnier, B., Darnon, C., & Butera, F. (2009). Faking the desire to learn: A clarification of the link between mastery goals and academic achievement. *Psychological Science*, *20*, 939–943. http://dx.doi.org/10.1111/j.1467-9280.2009.02384.x.

Elliot, A.J. (2005). A conceptual history of the achievement goal construct. In A.J. Elliot, & C. Dweck (Eds.), *Handbook of competence and motivation* (pp. 52–72). New York: The Guilford Press.

Gabriele, A.J., & Montecinos, C. (2001). Collaborating with a skilled peer: The influence of achievement goals and perceptions of partners' competence on the participation and learning of low-achieving students. *The Journal of Experimental Education*, *69*, 152–178. http://dx.doi.org/10.1080/00220970109600654.

Gimmig, D., Huguet, P., Caverni, J. -P., & Cury, F. (2006). Choking under pressure and working memory capacity: When performance pressure reduces fluid intelligence. *Psychonomic Bulletin & Review*, *13*, 1005–1010. http://dx.doi.org/10.3758/BF03213916.

Hulleman, C.S., Schrager, S.M., Bodmann, S.M., & Harackiewicz, J.M. (2010). A meta-analytic review of achievement goal measures: Different labels for the same constructs or different constructs with similar labels? *Psychological Bulletin*, *136*, 422–449. http://dx.doi.org/10.1037/a0018947.

Judd, C.M., & McClelland, G.H. (1989). *Data analysis: A model comparison approach*. San Diego: Harcourt, Brace, Jovanovich.

Judd, C.M., McClelland, G.H., & Ryan, C.S. (2009). *Data analysis: A model comparison approach* (2nd ed.). New York: Routledge Press.

Kane, M.J., Conway, A.R.A., Hambrick, D.Z., & Engle, R.W. (2007). Variation in working memory capacity as variation in executive attention and control. In A. Miyake, A.R.A. Conway, C. Jarrold, M.J. Kane, & J.N. Towse (Eds.), *Variation in working memory* (pp. 21–46). New York, NY: Oxford University Press.

Kane, M.J., & Engle, R.W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 336–358. http://dx.doi.org/10.1037/0278-7393.26.2.336.

Murayama, K., & Elliot, A.J. (2011). Achievement motivation and memory: Achievement goals differentially influence immediate and delayed remember–know recognition memory. *Personality and Social Psychology Bulletin*, *37*, 1339–1348. http://dx.doi.org/10.1177/0146167211410575.

Poortvliet, P.M. (2013). Harming others' task-related efforts: The distinct competitive effects of ranking information on performance and mastery goal individuals. *Social Psychology*, *44*, 373. http://dx.doi.org/10.1027/1864-9335/a000161.

Poortvliet, P.M., & Darnon, C. (2010). Towards a more social understanding of achievement goals: The interpersonal effects of mastery and performance goals. *Current Directions in Psychological Science*, *19*, 324–328. http://dx.doi.org/10.1177/0963721410383246.

Poortvliet, P.M., Janssen, O., Van Yperen, N.W., & Van de Vliert, E. (2009). Low ranks make the difference: How achievement goals and ranking information affect cooperation intentions. *Journal of Experimental Social Psychology*, *45*, 1144–1147. http://dx.doi.org/10.1016/j.jesp.2009.06.013.

Raghubar, K.P., Barnes, M.A., & Hecht, S.A. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and Individual Differences*, *20*, 110–122. http://dx.doi.org/10.1016/j.lindif.2009.10.005.

Ramirez, G., & Beilock, S.L. (2011). Writing about testing worries boosts exam performance in the classroom. *Science*, *331*(6014), 211–213.

Redick, T.S., Broadway, J.M., Meier, M.E., Kuriakose, P.S., Unsworth, N., Kane, M.J., et al. (2012). Measuring working memory capacity with automated complex span tasks. *European Journal of Psychological Assessment*, *28*, 164–171. http://dx.doi.org/10.1027/1015-5759/a000123.

Rosen, V.M., & Engle, R.W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General*, *126*, 211–227. http://dx.doi.org/10.1037/0096-3445.126.3.211.

Senko, C., & Harackiewicz, J.M. (2005). Achievement goals, task performance, and interest: Why perceived goal difficulty matters. *Personality and Social Psychology Bulletin*, *3*, 1739–1753. http://dx.doi.org/10.1177/0146167205281128.

Senko, C., Hulleman, C.S., & Harackiewicz, J.M. (2011). Achievement goal theory at the crossroads: Old controversies, current challenges, and new directions. *Educational Psychologist*, *46*, 26–47. http://dx.doi.org/10.1080/00461520.2011.538646.

Smeding, A., Darnon, C., Souchal, C., Toczek-Capelle, M.C., & Butera, F. (2013). Reducing the socio-economic status achievement gap at university by promoting mastery-oriented assessment. *PLoS ONE*, *8*, e71678.

Spencer, S.J., Steele, C.M., & Quinn, D.M. (1999). Stereotype threat and women's math performance. *Journal of Experimental Social Psychology*, *35*, 4–28. http://dx.doi.org/10.1006/jesp.1998.1373.

Spencer, S.J., Zanna, M.P., & Fong, G.T. (2005). Establishing a causal chain: Why experiments are often more effective than mediational analyses in examining psychological processes. *Journal of Personality and Social Psychology*, *89*, 845–851. http://dx.doi.org/10.1037/0022-3514.89.6.845.

Uittenhove, K., & Lemaire, P. (2013). Strategy sequential difficulty effects vary with working-memory and response–stimulus-intervals: A study in arithmetic. *Acta Psychologica*, *143*, 113–118. http://dx.doi.org/10.1016/j.actpsy.2013.02.007.

Unsworth, N., & Engle, R.W. (2005). Working memory capacity and fluid abilities: Examining the correlation between operation span and raven. *Intelligence*, *33*, 67–81. http://dx.doi.org/10.1016/j.intell.2004.08.003.

Unsworth, N., Heitz, R.P., Schrock, J.C., & Engle, R.W. (2005). An automated version of the operation span task. *Behavior Research Methods*, *37*, 498–505. http://dx.doi.org/10.3758/BF03192720.

Van Yperen, N.W. (2003). Task interest and actual performance: The moderating effects of assigned and adopted purpose goals. *Journal of Personality and Social Psychology*, *85*, 1006–1015. http://dx.doi.org/10.1037/0022-3514.85.6.1006.

Van Yperen, N.W., Blaga, M., & Postmes, T. (2014). A meta-analysis of self-reported achievement goals and nonself-report performance across three achievement domains (work, sports, and education). *PLoS ONE*, *9*(4), e93594. http://dx.doi.org/10.1371/journal.pone.0093594.

Van Yperen, N.W., Blaga, M., & Postmes, T. (2015). A meta-analysis of the impact of situationally induced achievement goals on task performance. *Human Performance*.

Van Yperen, N.W., & Leander, N.P. (2014). The overpowering effect of social comparison information (TOESCI): On the misalignment between mastery-based goals and self-evaluation criteria. *Personality and Social Psychology Bulletin*, *40*, 676–688. http://dx.doi.org/10.1177/0146167214523475.