Achievement Goals and Mental Arithmetic: The Role of Distributed Cognition

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Abstract

The purpose of these studies was to investigate the role of distributed cognition in defusing the impact of evaluative pressure caused by performance-approach goals on mental arithmetic performance. Performance-approach goals can generate worrying thoughts that can deplete working memory resources. However, some of these working memory limitations can be compensated by off-loading the internal cognitive process to the external environment. We tested this prediction in two experiments. Participants carried out modular arithmetic tasks in a performance-approach goal or mastery-approach goal condition crossed with interactivity or no interactivity. Performance-approach goal manipulation hampered cognitive performance (accuracies), (Experiment 1). However, these negative effects were defused with the help of interactivity (Experiment 2). Interestingly, the mastery-focused individuals had a performance drop in the interactive condition (Experiment 1 and Experiment 2). Finally, experiment 2 reported higher maths anxiety levels for the performance-focused individuals. Reasons for the findings and future implications will be discussed.

Keywords: achievement goals; working memory, mental arithmetic; distributed cognition; interactivity

Introduction

Achievement goals are said to reflect the aim of an individual's achievement pursuits. They are frameworks that can help to understand how individuals react to various achievement situations (Poortvliet & Darnon, 2010). There is a wealth of research on achievement goals and their effects on academic performance. But much less is known about the cognitive processes of these goals and particularly the effects on the working memory and whether distributed cognition could be used to reduce the negative effects of performance goals on academic performance.

Achievement goals

Individuals pursuing performance-approach goals are good at knowing the material that is essential for the task in hand (Elliott, Shell, Henry, & Maier, 2005). They listen to the cues about the future assignments and adjust learning based on these cues. Students perform better when they focus on topics that the teacher deems important and that are tested (Broekkamp, Hout-Wolters, & Van Hout-Wolters, 2007). Performance-focused students concentrate on memorizing rather than elaboration and knowledge construction (Entwistle, 1988). This can lead to surface learning and rote learning (Harackiewicz & Linnenbrink, 2005). Mastery-focused students are freer to pursue their own agenda guided by their own personal interests and curiosity of the current topic. Hence, mastery-approach goals predict the use of adaptive cognitive strategies that lead to deeper processing. This kind of approach might benefit the students in the long run as it promotes deeper learning but might not help in gaining the highest grades as it is based on personal interests rather than the areas that might be tested. When people pursue performance-approach goals, their focus is on the outcome of the task and therefore the individuals might not be fully engaged with the process. On the contrary, mastery-focused individuals focus on the process rather than the activity of outperforming others. Mastery-focused individuals focus on learning and their personal improvement, and therefore have a focus on the task that allows them to explore both intrinsic and utility value (Hulleman, Durik, Schweigert, & Harackiewicz, 2008).

The Effects of Performance-approach Goals on Working Memory

The pressure of outperforming others can generate concerns that deplete available working memory resources. (Crouzevialle & Butera, 2013). When high working memory load tasks were utilized, there was a performance drop in the high evaluative pressure condition (Beilock, Holt, Kulp, & Carr, 2004). Additionally, Avery and Smillie (2013) examined the influence of achievement goal pursuits on working memory capacity when varying levels of executive load were used. Under the high executive load, there was poorer working memory processing during the performance-approach goal than when mastery-approach goal or no-goal control were used (Avery & Smillie, 2013).

Distributed Cognition

Some of the possible working memory limitations can be compensated by off-loading the cognitive process to the external environment (e.g., by using pen and paper), (Neth & Payne, 2011). According to Kirsh (2010), cognitive processes go to wherever it is easier to perform them. It might be easier to understand a particular sentence by drawing a picture of it rather than just thinking internally. Therefore, with the help of drawing the overall cognitive cost of sense making can be reduced (Kirsh, 2010). Kirsh (1995) conducted a simple coin counting experiment where he observed that complementary strategies could enhance performance (Kirsh, 1995). Neth and Payne (2011) asked participants to add coins on a computer screen in move versus look conditions. Accuracy increased with interactivity but not the speed. Both accuracy and speed were increased with the help of using hands (in the pointing condition) when counting arrays of items (simple arithmetic task), (Carlson, Avraamides, Cary, & Strasberg, 2007). Interactivity enhanced performance, and in particular, accuracy and efficiency for longer sums involving 11 single-digit numbers (Vallée-Tourangeau, 2013). Additionally, interactivity allows the agent to extend their working memory resources when there is a need for it. Dyslexic children (aged between 9 – 11 years) benefited the most form rearranging the letter tiles (interactive condition) in a word production task. By reshaping the physical presentation of the letters, their less efficient working memory capabilities could be compensated. The control group (typically developing children) did not benefit from externalizing the process. In fact, their performance was poorer (with easy set of letters) when they manipulated the letter tiles to produce words (Webb & Vallée-Tourangeau, 2009).

Maths anxiety

Maths anxiety is a multidimensional construct, and a full list of the causes is still undetermined. Maths anxiety can be defined as a feeling of apprehension and tension in a mathematical setting which can also affect overall mathematics performance. The highly maths-anxious individuals avoid mathematics as a topic and choose fewer elective mathematics courses in secondary school and university (Ashcraft, 2002). The maths-anxious individual is pre-occupied with the maths fears and the overall capacity of working memory gets affected. This pre-occupation functions as a secondary task that is heavily working memory resource demanding (Ashcraft & Krause, 2007). Maths anxiety causes a transitory disruption of working memory. The lower working memory capacity of high maths-anxious individuals is partially responsible for the maths performance decrements. This reduced working memory capacity is on-line effect that disrupts information processing in maths tasks (Ashcraft & Kirk, 2001). Finally, maths anxiety is higher among women than men (Ashcraft & Faust, 1994; Luttenberger, Wimmer, & Paechter, 2018). To increase the chances of selecting maths-anxious individuals, we included women only in the sample.

Experiment 1

The aim of the current study was to understand how mastery-approach goal and performance-approach goal engage working memory resources and whether interactivity could be used to reduce any of the negative effects of performance-approach goals on maths performance. If the working memory is loaded due to outcome related worry then there is additional taxation on the working memory (Crouzevialle & Butera, 2013). And together with the horizontally presented maths problems (modular arithmetic tasks) there can be maths performance decrements when in the performance-approach goal condition (Beilock, 2008). We reasoned that, if worries of outperforming others lead to poor maths performance, then giving students the opportunity to externalize the internal cognitive process would enhance this performance.

Method

Participants

Forty-one female undergraduate psychology students (M = 21.88 SD = 3.90) participated in this study for exchange of credits. After consenting to participate in the study, subjects were randomly assigned to one of the experimental conditions (performance-approach goal or mastery-approach goal crossed with interactivity or no interactivity). The participants were tested individually (15 minutes) in a psychology lab.

Material and Measures

Arithmetic task There were two blocks of 24 modular arithmetic tasks that relied heavily on working memory resources, adapted from Beilock and Carr (2005). The purpose of the tasks is to judge the validity of maths problems like $61 \equiv 18 \pmod 4$. The middle number is subtracted from the first number (i.e. 61-18) and then the difference is divided by 4. If the answer is a whole number the maths problem is true (Beilock & Carr, 2005). Modular arithmetic tasks as laboratory tasks are advantageous as most students have not seen them before and therefore previous task experience is controlled.

High-demand problems (e.g. $42 \equiv 27 \pmod 3$) requiring a double-digit subtraction operation were used as they required borrowing, resulting in using more working memory resources. Half of the maths problems required a true response by the participant. The order of the questions was randomized and each question was asked only once. The original questions used by Beilock and Carr (2005) were a mixture of high demand problems (two-digit numbers requiring borrowing) and low-load questions (single-digit numbers, without borrowing). The current study used the high-demand problems only because of limited benefits of using interactivity with low-demand tasks.

The modular arithmetic tasks were presented in a horizontal format as opposed to a vertical format (also called column subtraction). The horizontal presentation of the maths problems is more reliant on phonological resources (the verbal resources) because individuals maintain the required problem steps in their memory verbally (DeStefano & LeFevre, 2004). The possible worries of performing better than others places much heavier demands on working memory (phonological loop, in particular).

Experimental manipulations Participants were informed after completing the baseline block of modular arithmetic tasks (24) that they required to complete a second block (24) of modular arithmetic tasks, and this time their performance would be recorded. The participants in the performance-approach goal condition read the following instructions before starting the task that were aimed at activating performance-approach goals (Darnon, Harackiewicz, Butera, Mugny, & Quiamzade, 2007):

"During the recorded part of the task, the experimenters will assess your performance. It is important for you to be proficient, to perform well and obtain a high score, in order to demonstrate your competence. You should know that a lot of students will do this task. You are asked to keep in mind that you should try to distinguish yourself positively, that is, to perform better than majority of students. In other words, what we ask you here is to show your competencies, your abilities."

The participants in the mastery-approach goal condition read instructions that were designed to activate mastery-approach goals. There is no social comparison being made and the instructions are aimed to create task interest, use for everyday life, and there is no mention about scores or task performance (Crouzevialle, Smeding, & Butera, 2015).

"In previous research, we have observed that practice of the arithmetic task you are solving right now benefits to cognitive functioning and leads to a progressive improvement of mental processes. Hence, this task solving can proved to be beneficial on the long-term. It is however necessary that you focus your attention on calculation mastery, so as to quickly and accurately solve each problem, in order to experience these benefits. Try to master this task as much as you can; keep in mind its practice can be beneficial to you."

Interactivity The participants in the interactive condition were allowed to use pen and paper. The participants in the non-interactive condition were not allowed to use any external artefacts to complete the task.

Procedure

After consenting to participate in the study, the participants were randomly assigned to one of the experimental conditions. There was a short training session before starting the first block. The first block of questions (24) functioned as a base-line. The participants were told that it was a training block, and that their performance was not recorded to avoid any achievement goal activation. The second block of questions was done under the experimental conditions. The participants were told that their performance was recorded this time.

Results

Accuracy

Before the actual statistical analysis was conducted, it was concluded that there were no group differences between the participants in the mastery-approach goal condition and performance-approach goal condition on the baseline modular arithmetic performance (block 1), $F(1, 37) = .08$, $p = .78$, $\eta_p^2 = .002$, confirming that the groups did not differ in their ability to complete the modular arithmetic tasks. Our main performance measure was accuracy of the high working memory load tasks. Accuracy difference score was calculated by subtracting the modular arithmetic performance of block 1 from block 2. Furthermore, a difference score in latencies was used as a covariate in order to avoid any speed-accuracy trade-off of the participants. A 2 (instruction: performance-approach goal or mastery-approach goal) x 2 (level of interactivity: interactivity or control) between-groups analysis of covariance (ANCOVA) was conducted. The covariate, difference score in latencies, was significantly related to the modular arithmetic accuracy, $F(1, 36) = 5.76$, $p =.02$, $\eta_p^2 = .14$. There was a significant two-way interaction of interactivity (interactivity or control) and instruction (performance-approach goal or mastery-approach goal), $F(1, 36) = 4.39$, $p = .043$, $\eta_p^2 = .11$. As expected, performance-focused participants had lower maths performance in the non-interactive condition ($M = -7.43$, $SE = 2.50$) than the mastery-approach goal individuals ($M = 5.44$, $SE = 2.38$), (Figure 1). The post hoc tests confirmed this finding, $F(1, 18) = 11.1$, $p = .004$, $\eta_p^2 = .38$. However, mastery-focused individuals had a performance drop in the interactive condition ($M = -2.37$, $SE = 2.50$) compared with their performance in the non-interactive condition ($M = 5.44$, $SE = 2.38$), (Figure 1). Post hoc tests confirmed this finding, $F(1, 18) = 4.90$, $p = .04$, $\eta_p^2 = .21$. Additionally, there was a main effect of instruction (mastery-approach goal or performance-approach goal), $F(1, 36) = 9.72$, $p = .004$, $\eta_p^2 = .21$. The modular arithmetic performance of the mastery-approach goal participants was enhanced from block 1 to block 2 ($M = 1.53$, $SE = 1.72$). As predicted, there was reduced modular arithmetic performance of the performance-approach goal participants ($M = -6.16$, $SE = 1.76$). Finally, interactivity did not improve modular arithmetic performance, $F(1, 36) = 1.13$, $p = .30$, $\eta_p^2 = .03$.

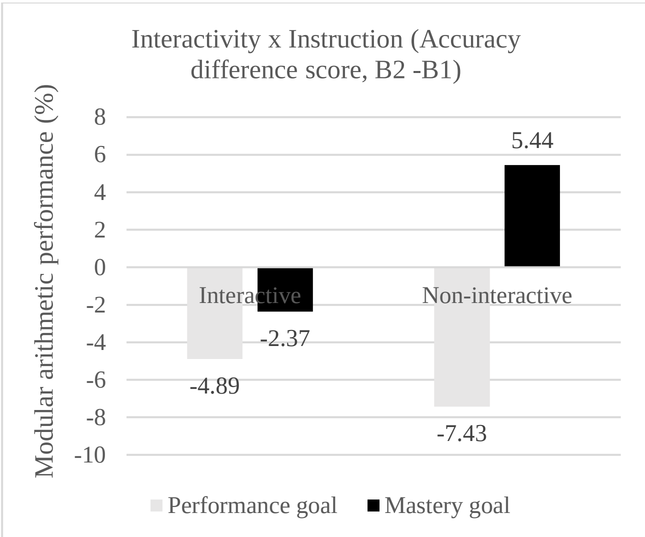

Figure 1: Mean difference in modular arithmetic performance (%) as a function of experimental condition (Experiment 1).

Discussion

We found that when the performance-approach goal was made salient, there was a drop in the mental arithmetic performance compared with the mastery-approach goal participants. Additionally, an interesting finding was made in relation to mastery-focused individuals, their modular arithmetic performance was reduced when the participants were allowed to interact with external resources (with the use of pen and paper).

Experiment 2

It was clear from Experiment 1 that the mental arithmetic performance of the performance-focused participants was depleted compared to the mastery-goal individuals. We therefore argued that it would be the performance-focused individuals that would show higher levels of maths anxiety due to the worrying thoughts of outperforming others, in a mathematical domain. Experiment 2 therefore measures maths anxiety of the participants both before the experiment (trait maths anxiety) and after (state maths anxiety). If maths anxiety is elevated when performance-approach goal is made salient then there should be more benefits of externalizing the internal cognitive process to the outside world (interactivity) for the performance-focused individual.

Method

Participants

Seventy-eight female undergraduate psychology students (*M* = 19.12, *SD* = 1.60) participated in this study for exchange of credits. This study only included females due to their higher levels of maths anxiety. After consenting to participate in the study, the participants were randomly assigned to one of the experimental conditions. The participants were tested individually in a psychology lab (40 minutes).

Material and Measures

Mathematics anxiety (trait) Maths anxiety was measured with the 23-item Mathematics Anxiety Scale (MAS-UK) by Hunt, Clark-Carter, and Sheffield (2011). The test comprises statements that relate to everyday situations that have a mathematics component (e.g., adding up a pile of change). The participants are expected to respond by confirming the level of anxiety that they feel on a 5-point Likert-type scale.
Basic arithmetic skills Basic arithmetic skill (BAS) was measured with the help of 45 simple expressions in a 60-second period (e.g. 10-5).
Computation span (Working memory) Working memory capacity was measured with the help of a computation-based span test. The participants were asked to read a simple arithmetic expression (e.g. 5 + **2** = ?, 9 – **6** = ?) and announce their answer aloud to the researcher (7, 3). Additionally, the participants were asked to remember the second number of each equation to be recalled later (**2**, **6**). The sequences of the simple arithmetic tasks varied from 1 to 7 tasks. The computation span task requires both on-line processing for the problem solution which is simultaneous with storage and maintenance of information in working memory for serial recall. People with maths anxiety have smaller working memory spans. This smaller span can lead to increased reaction times and errors when mental mathematics is completed at the same time as a memory load task (Ashcraft & Kirk, 2001).
Arithmetic task The mental arithmetic task consisted of modular arithmetic tasks (two blocks of 24 questions) that relied heavily on working memory resources, adapted from Beilock and Carr (2005). The arithmetic task was identical to Experiment 1.
Mathematics anxiety (state) Maths anxiety was measured with the 23-item Mathematics Anxiety Scale (MAS-UK) by Hunt, Clark-Carter, and Sheffield (2011). This test was the same as the trait measurement used earlier during the experiment but this time referring to present time (now).
Experimental manipulations Participants were informed that after completing the baseline block of modular arithmetic tasks (24) that they required to complete a second block (24) of modular arithmetic tasks, and this time their performance would be recorded. The actual priming instructions were identical with the experiment 1.
Interactivity As before the participants in the interactive condition were allowed to use pen and paper to come to the solution. The participants in the non-interactive condition were not allowed to use any external artefacts.

Procedure

After consenting to participate in the current study, the participants started with the trait maths anxiety questionnaire. This was then followed by the timed basic arithmetic skills test. Before commencing with the modular arithmetic tasks in primed conditions, computation span (working memory capacity) was assessed. There was a short training session (2 questions) before starting the first block of the modular arithmetic problems (24). Only high-demand problems requiring a double-digit subtraction operation (e.g. $42 \equiv 27$ (mod 3)) were used as they required more of the working memory resources compared to low-demand problems (single-digit operation, and no carrying required) (Ashcraft & Kirk, 2001). After the baseline the participants were primed to either performance-approach goal condition or mastery-approach goal condition. If in the interactive condition, the use of pen and paper was allowed. After completing the second block of arithmetic tasks in primed conditions, the participants were asked to complete the state maths anxiety questionnaire.

Results

Accuracy

There were no group differences between the participants in the two achievement goal groups on the baseline modular arithmetic performance (block 1), $F(1, 74) = 1.77$, $p = .19$, $\eta_p^2 = .02$, confirming that the groups did not differ in their ability to complete the modular arithmetic tasks. Additionally, there were no group differences in working memory capacity, $F(1, 74) = 1.17$, $p = .28$, $\eta_p^2 = .02$, confirming the fact that the two achievement goal groups did not differ in their level of working memory capacity as a baseline measure. To test the hypotheses, accuracy difference in percentage score (block 2 - block 1) of the modular arithmetic tasks was examined. A 2 (level of interactivity: interactivity or control) x 2 (instruction: performance-approach goal or mastery-approach goal) between-groups analysis of covariance (ANCOVA) was conducted. There was a significant two-way interaction of interactivity (interactivity or control) and instruction (mastery-approach goal or performance-approach goal) after controlling for a difference score in latencies, $F(1, 73) = 10.04$, $p = .002$, $\eta_p^2 = .12$. The performance-focused participants benefited from the use of interactivity ($M = 3.70$, $SE = 1.80$) unlike the mastery-focused individuals whose performance was depleted with interactivity ($M = -3.30$, $SE = 1.90$), (Figure 2). The post-hoc test confirmed this finding, $F(1, 36) = 10.67$, $p = .002$, $\eta_p^2 = .23$. The accuracy of the mastery-approach goal participants was reduced in the interactive condition ($M = -3.30$, $SE = 1.90$) compared with the non-interactive condition ($M = 5.40$, $SE = 1.80$) (Figure 2). This finding was confirmed with a post-hoc test, $F(1, 36) = 6.82$, $p = .01$, $\eta_p^2 = .16$. The two main effects (interactivity or instruction) did not reach statistical significance. There was no significant difference in accuracy between the participants in the interactive condition and the participants in the non-interactive condition, $F(1, 73) = 2.35$, $p = .13$, $\eta_p^2 = .03$. Additionally, the main effect of instruction (mastery-approach goal or performance-approach goal) did not reach statistical significance ($F < 1$).

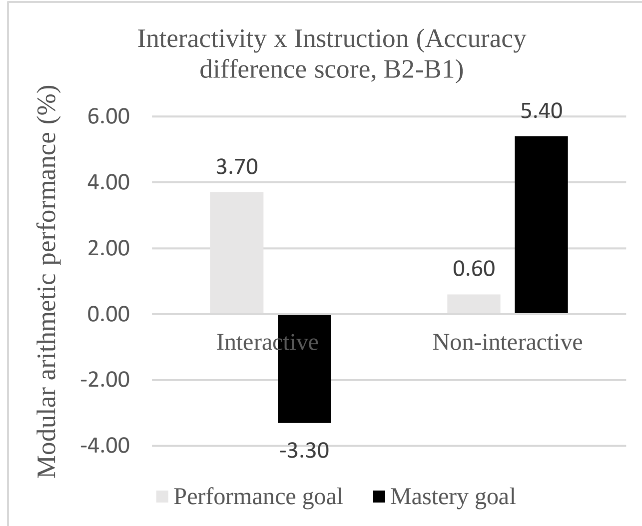

Figure 2: Mean difference in modular arithmetic performance (%) as a function of experimental condition (Experiment 2).

Maths anxiety (state)

A two-way between groups analysis of covariance (ANCOVA) was conducted to compare the effects of interactivity on two levels of instructions that were given to the participants (mastery-approach goals or performance-approach goals) when completing the modular arithmetic tasks. Participants' scores on maths anxiety (trait) were used as the covariate in this analysis. After adjusting for pre-existing maths anxiety levels (trait maths anxiety), there was a significant main effect of instruction (mastery-approach goal or performance-approach goal) on state maths anxiety, $F(1, 73) = 6.07$, $p = .02$, $\eta_p^2 = .08$. The performance-focused individuals showed higher levels of maths anxiety after completing the experiment in primed conditions ($M = 56.0$, $SE = 1.98$) than the mastery goal participants ($M = 49.1$, $SE = 1.98$) confirming the hypothesis set in the beginning. The main effect of interactivity did not reach statistical significance, $F < 1$, as did not the two-way interaction of instruction and interactivity either.

General discussion

The purpose of this study was to see whether the adverse effects of performance-approach goals on mental arithmetic performance could be alleviated with the use of distributed cognition. This investigation reported a performance drop in mental arithmetic performance for the performance-focused individuals in the non-interactive condition compared with the mastery-approach goal individuals (Experiment 1). However, interactivity mitigated the negative effects of performance-approach goal instructions on maths performance (Experiment 2). Additionally, we found that performance-focused participants felt higher levels of state maths anxiety, after completing the maths tasks (Experiment

2). Clearly, the priming instructions of performance-approach goals had strong carry-on effects on maths anxiety as they were still felt after completing the mental arithmetic tasks. However, it was evident that there were no carry-on effects of interactivity at the end of the experiment. An interesting finding was made as there was reduced maths performance for the mastery-focused individual in the interactive condition (Experiment 1 and Experiment 2). It was clear that distributed cognition hindered maths performance for the mastery-focused individual who was less maths anxious after the experiment but allowed the more maths-anxious individual (the participants in the performance-approach goal) to improve mental arithmetic performance. Similar findings have been made by Webb and Vallée-Tourangeau (2009) who concluded that when the agent had the required cognitive resources to complete the word production task, interactivity hampered the performance. If working memory resources are not compromised from increased maths anxiety levels (like in the mastery-approach goal environment), then there are little benefits of externalising the internal cognitive process to the outside world.

Conclusion

To allow for a successful distributed cognition outcome it is of importance to understand how individuals are affected by the different achievement goals. Clearly, the effective manipulation of the physical problem space is relative to the level of the task difficulty (e.g., modular arithmetic tasks) as well as the cognitive abilities (working memory resources in particular) of the individual. Finally, it is important to consider the implications of these studies on a practical level. Future mathematics education should take into consideration the findings of these two experiments in a way to make the learning experience more interactive for the more maths-anxious individuals (performance-focused individuals). The maths-anxious individual should be given the opportunity to reshape the presentation of the mathematical problems to extend their cognitive systems. By doing this, the working memory capacity can be augmented and as a consequence, the maths performance enhanced.

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