Endogenous and Exogenous Time Pressure:

Interactions with Mathematics Anxiety in Explaining Arithmetic Performance

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Abstract

Eighty adults performed mental arithmetic under endogenous (time limit) or exogenous (presence of a clock) time pressure. Results demonstrated a significant interaction between math anxiety and endogenous pressure: error rates were significantly greater among high math anxious individuals when given a time limit. A significant interaction was observed between exogenous time pressure and math anxiety: performance of low math anxious individuals was reduced when a clock was present. Effects were only present in response to problems involving a carry operation, supporting previous findings that math anxiety may be particularly detrimental on math problems that rely more on working memory resources. The findings suggest that the type of time pressure may need to be taken into account when designing assessments.

Keywords: math anxiety; mental arithmetic; time pressure; performance

1. Introduction

Research has demonstrated a consistent relationship between math anxiety and arithmetic performance (Hembree, 1990; Ma; 1999). However, the relationship is more complex than it appears. For example, studies have shown that math anxiety effects are greater in response to math problems that place higher demands on working memory, particularly those problems involving a carry operation (Ashcraft & Faust, 1994; Faust, Ashcraft & Fleck, 1996), suggesting that math anxiety consumes valuable working memory resources. This was explored further by Ashcraft and Kirk (2001) who gave low and high math anxious participants a math task involving carry and no-carry problems. They were also given either a two-letter (low working memory load) or six-letter (high working memory load) concurrent task. Performance in the low load condition did not differ as a function of math anxiety, but in the high load condition high math anxious individuals performed significantly worse on problems that required a carry operation. The results suggest that math anxiety may be particularly detrimental on math problems that rely more on working memory resources.

However, there have been alternative suggestions concerning the mechanisms that underpin the relationship between math anxiety and performance, including the suggestion that math anxiety may be related to a deficient inhibition mechanism. That is, an inability to inhibit task-irrelevant distractors. Indeed, Hopko, Ashcraft, Gute, Ruggiero & Lewis (1998) provided evidence of a weakened disinhibition mechanism among highly math anxious individuals, albeit not specific to math stimuli. However, in a later study using a card version of the numeric Stroop task, Hopko, McNeil, Gleason and Rabalais (2002) found evidence that high math anxious individuals have an inability to inhibit attention towards irrelevant information. They observed that the high math anxious group took significantly longer to respond in the numeric task compared to the control (letter) task, whereas no significant difference was observed in the low math anxious group.

In addition to the observed effects on math performance, math anxiety has been shown to be related to the general avoidance of math, as reported in Hembree's 1990 meta-analysis. It has also been discussed in terms of local-avoidance, with very highly math anxious individuals responding quickly to more difficult math problems, possibly as a speed-accuracy trade-off (Ashcraft & Faust, 1994). Interestingly, Roskes, Elliot, Nijstaf and De Dreu (2013) studied the effect of time pressure as a function of avoidance motivation versus approach motivation. The former represents striving to avoid failure and was measured by scale items such as "when it looks like something bad could happen, I have a strong urge to escape". The researchers observed that performance was particularly negatively affected under time pressure among those who are avoidance motivated. In this instance time pressure was induced by setting a time limit for each math problem. Roskes et al discuss the findings partly in relation to avoidance motivation evoking a processing style that is resource demanding, with factors such as time pressure adding to the already limited cognitive resources available for task engagement. This proposition has parallels with an attentional control account of anxiety effects on cognitive performance (Eysenck, Derakshan, Santos & Calvo, 2007). According to attentional control theory, anxiety causes an imbalance between the stimulus-driven attentional system and the goal-directed attentional system. Math anxiety as an inhibition/attentional control deficit can be conceptualised in terms of how math anxious individuals may attend to information that is not part of the goal-directed attentional system. This may be in the form of exogenous task-irrelevant distractors, or in the form of intrusive or worrisome thoughts that impede or consume working memory resources (Hopko et al., 1998).

There is some evidence to suggest that worrisome thoughts are indeed associated with math anxiety. For example, Hunsley (1987) found that self-reported math anxiety accounted for a significant proportion of variance in negative internal dialogue experienced during a math exam. Also, DeCaro, Rotar, Kendra and Beilock (2010) observed a significant negative correlation between the number of self-reported task-related thoughts and problem solving accuracy. However, the nature of worrisome thoughts proposed to be experienced as a result of math anxiety has been somewhat speculative, although there are some empirical findings that indicate what such thoughts may consist of. For example, Beilock, Kulp, Holt and Carr (2004) asked participants to perform arithmetic in a high pressure condition and noted that they had significantly higher perceptions of performance pressure than those in the low pressure condition. In the high pressure condition participants were also more likely to report thoughts and worries about the situation and its consequences.

Faust et al (1996) provided some evidence to suggest that time pressure creates an increased cognitive load, which particularly impacts individuals high in math anxiety. They observed that the negative consequences of math anxiety disappeared when participants were tested in an untimed paper-and-pencil condition, in which cognitive load was reduced. To directly assess the relevance of time pressure on the relationship between math anxiety and performance, Kellogg, Hopko and Ashcraft (1999) gave low and high math anxious individuals a series of math problems under timed and untimed conditions. They observed an overall positive relationship between math anxiety and number of errors made, but this did not vary according to timed or untimed conditions, suggesting that time pressure may not be as important as first predicted in explaining the effect of math anxiety on performance. Kellogg et al (1999) suggested that task-related cognitions may be more directly related to factors other than time pressure, such as the presentation of math stimuli or physiological arousal. However, recent work has demonstrated that, even under non-timed conditions, 49.2% of participants self-reported having thought about time pressure during an arithmetic test situation. Moreover, self-reported math anxiety was significantly higher among those who had experienced thoughts about time pressure (Hunt, Clark-Carter & Sheffield, 2014).

Furthermore, in their study, Kellogg et al allowed participants to utilise the blank space on the paper provided to write down their workings out. It is possible that this approach might actually benefit high math anxious individuals, such that fewer working memory resources are required compared to maintaining calculation steps in working memory (c.f. Faust et al., 1996). As such, the findings of Kellogg et al cannot be generalised to all test situations.

It is feasible that the precise way in which time pressure is implemented is important in studying the effects of math anxiety. For example, time pressure could include: an overall predetermined timeframe that participants have to complete a task, smaller timeframes in which to complete sub-tasks or individual items, a modified timeframe based on an individual's concurrent performance, notification of the start and end of a task, regular verbal and visual reminders of time remaining, and constant verbalisation or visualisation of time remaining. Bosmans and De Smedt (2015) tested math performance of children under timed and untimed conditions and observed a significant negative direct relationship between math anxiety and performance in both conditions. In their study, the timed condition required participants to respond to columns of math problems, solving as many as possible within one minute, demonstrating one particular way of creating a timed condition. Also, Bosmans and De Smedt did not test the effect of time pressure on performance as a function of problem type, which, as discussed previously, is an important factor to consider when testing math anxiety effects on arithmetic performance.

Surprisingly little research has been conducted into the precise nature of time pressure and how this may relate to math anxiety and arithmetic performance. Moreover, consistent findings concerning the relationship between math anxiety and intrusive thoughts about pressure, and even time pressure specifically, warrant further investigation. In the context of math anxiety, the extent to which time pressure acts as an endogenous distractor and gives rise to intrusive thoughts has not been considered in relation to exogenous distractors that act as a constant reminder of the time. Given that real-world test scenarios, such as exam halls, often involve a constant visual reminder of the time in the form of a clock, the current study manipulated time pressure by asking participants to perform mental arithmetic problems under time pressure or no time pressure, with or without the presence of a clock. It was hypothesised that self-reported math anxiety would have a negative effect on arithmetic performance, but this would be particularly noticeable on problems that involve a carry operation. Also, it was predicted that math anxiety effects on performance would be exacerbated in the timed condition and that a performance detriment would be further enhanced by the presence of a clock.

2. Method

2.1 Design

A four-way mixed experimental design was employed to investigate the effects of math anxiety, problem type, time pressure and presence of a clock on mental arithmetic performance. Participants completed a series of math problems presented using a verification task in which response time (seconds) and number of errors were recorded. Math anxiety groups were created via a median split and consisted of those low in math anxiety and those high in math anxiety according to scores on the self-report measure taken. Math problems were dichotomised according to inclusion of a carry term. Half of participants completed the math task under time pressure and half under no time pressure. In half of cases a clock was visible to participants during task performance and in half of cases a clock was not visible.

2.2 Participants

Participants were 80 (22 men, 58 women) undergraduate psychology students, from XXXX, U.K. The sample included participants from all three years of undergraduate study. Ages ranged from 18 to 47 years (mean = 24.95; SD = 8.76). The mean age is consistent with the trend for older students to enter university in the U.K in recent years (Universities Colleges and Admissions Service, 2014). Participants came from an opportunity sample of the general university population gained via advertising at the university.

2.3 Self-reported math anxiety

Math anxiety was measured using the Mathematics Anxiety Scale-U.K. (MAS-U.K., Hunt, Clark-Carter & Sheffield, 2011). The MAS-U.K. has 23 items and uses a five-point Likert-type scale. Participants are asked to respond how anxious they would feel in a variety of situations involving math, with higher scores representing higher levels of math anxiety. The scale has high test-retest reliability (r = .89) and excellent internal consistency (Cronbach's alpha = .96).

2.4 Experimental stimuli and equipment

Experiment software Authorware was used to present 120 two-digit mental arithmetic addition problems, e.g. 16 + 43 = 59. 80 problems had a proposed solution that was true, with the remaining 20 false problems used to facilitate the verification task; the proposed solution was +/- 3 from the correct answer. Addends were randomly selected from the range 13 to 57, excluding digits ending in zero. Half the problems required a carry operation, e.g. 27 + 16 = 43, with problem size controlled and inclusion of a carry term counterbalanced across true and false problems. The task was presented via a standard flat screen computer with a resolution of 1280 x 1024. Stimuli were in black Arial, 72 point bold font and were presented in the centre of the screen. True and false options were presented directly below each math problem and all responses were actioned through a computer mouse and cursor. In conditions where a clock was visible to students, a standard 12-hour (7cm x 7cm) analogue clock with Arabic numerals was used, with a black rim and white background.

2.5 Procedure

Participants gave informed consent to take part in a study of mental arithmetic performance, aware of the task requirements but unaware of the four conditions (time pressure & clock; time pressure & no clock; no time pressure & clock; no time pressure & no clock). Firstly, participants completed the MAS-U.K. (Hunt *et al.*, 2011) then individuals were randomly allocated to one of the conditions and were seated alone, in front of a personal computer in research cubicles located on the university campus. In conditions where a clock was made visible to participants, this was situated to the right side of the computer screen, level with the base of the screen. To control for general object-distraction, in conditions where a clock was not visible the clock was located in the same place but was covered. In all conditions the toolbar on the computer screen was hidden so the time was not visible on-screen. Those performing under time pressure were given a 15-minute time limit, where the researcher verbalised the start and end of the time period; initial piloting indicated this allowed sufficient time for participants to complete the task and also provides a valid degree of time pressure. Participants were given instructions regarding how to respond and were instructed to place their hand on the computer mouse. All participants completed 5 practice trials prior to the main set of trials, whereby problems remained on-screen until individuals responded true or false. Upon responding to each problem, a pause screen appeared displaying a non-math symbol until the participant pressed any key to continue to the next trial. Problems were randomly presented. Once participants had completed the math task they were thanked and debriefed.

3. Results

3.1 Data Screening

As indicated by a Kolmogorov-Smirnov test ($p = .09$) and visual inspection of a histogram, the overall distribution of math anxiety scores was normal, which is consistent with previous studies (Hunt *et al.*, 2014). With the exception of a small degree of positive skew in the no-time pressure/presence of a clock condition (p = .04), math anxiety scores were normally distributed in all other experimental conditions ($p > .05$). The variance of math anxiety scores did not vary greatly across conditions, whereby the highest variance (357.21) was less than four times the value of the lowest (100.24) (Clark-Carter, 2010). Regarding the dependent variables, a Kolmogorov-Smirnov test indicated significant deviation from normality for both error rates and response times ($p < .05$). However, visual inspection of histograms suggested an approximately normal distribution for response times. Error rates showed slight positive skew, although ANOVA is sufficiently robust minor violations of parametric assumptions (Clark-Carter, 2010). Variance scores for response times appeared homogenous across experimental conditions, whereby the highest variance was no more than four times the value of the lowest. However, variance scores for error rates appeared to vary across conditions; as such adjustments were made to the degrees of freedom in any necessary tests following ANOVA.

3.2 Main Analyses

Two four-way mixed ANOVAs were performed to investigate the effects of math anxiety, problem type, presence of a clock, and time pressure on error rates and response time. Firstly, concerning error rates, there was no significant main effect of math anxiety. However, there was a significant main effect of problem type, $F(1, 72) = 34.29$, $p < .001$, $\eta 2 = .07$, such that more errors were made in response to carry problems. There was no significant main effect of time pressure or presence of a clock, although a significant interaction was observed between math anxiety level and time pressure, $F(1, 72) = 5.55$, $p = .021$, $\eta 2 = .04$, such that error rate was consistently low among low math anxious individuals, but, in the time pressure condition, high math anxious individuals performed worse than in the no-pressure condition. Further to this, significant interactions were demonstrated between problem type and time pressure, $F(1, 72) = 10.39$, $p = .002$, $\eta 2 = .02$, and problem type and presence of a clock, $F(1, 72) = 7.56$, $p = .008$, $\eta 2 = .02$, such that time pressure and presence of a clock negatively impacted performance only on problems that involved a carry operation. Finally, three-way interactions were observed between math anxiety, problem type and time pressure, $F(1, 72) = 5.19$, $p = .03$, $\eta 2 = .01$, and math anxiety, problem type and presence of a clock, $F(1, 72) = 4.94$, $p = .03$, $\eta 2 = .01$.

Follow-up analyses on no-carry problems, showed no significant interactions between math anxiety and time pressure and presence of a clock. However, focusing on carry problems only, significant two-way interactions existed between math anxiety and time pressure, $F(1, 76) = 5.90$, $p = .02$, $\eta 2 = .06$, and presence of a clock, $F(1, 76) = 5.83$, $p = .02$, $\eta 2 = .06$. Post hoc analysis with an adjusted alpha of .025 showed that time pressure had no significant effect on error rates among low math anxious individuals, $t(38) = .31$, $p = .76$, $d = 0.10$. However, a Welch's t-test with adjusted degrees of freedom to account for heterogeneity of variance, showed that time pressure significantly negatively impacted performance among high math anxious individuals, $t(31.41) = 3.88$, $p < .001$, $d = 0.98$, resulting in a mean difference of 3.15 errors (see Fig. 1) and representing a large effect size according to Cohen's (1988) guidelines. Regarding presence of a clock, this had no significant effect on performance among those high in math anxiety, $t(38) = .49$, $p = .63$, $d = 0.16$, but a Welch's t-test showed the presence of a clock had a significant negative impact on performance among those low in math anxiety, $t(21.04) = 5.44$, $p < .001$, $d = 1.72$, resulting in a mean difference of 2.35 errors (see Fig. 2) with a very large effect size. All means and standard deviations can be seen in Table 1.

Turning to response time, there was a significant main effect of problem type, $F(1, 72) = 180.49$, $p < .001$, $\eta 2 = .20$, such that participants took longer to respond to problems involving a carry operation. Also, there was a significant main effect of math anxiety, $F(1, 72) = 4.95$, $p = .03$, $\eta 2 = .04$, such that response time was longer among high math anxious individuals. No other significant effects were observed. All means and standard deviations can be seen in Table 2.

Post hoc analysis to test for a possible speed-accuracy trade-off among high math anxious individuals responding to carry problems demonstrated a significant negative correlation between number of errors and response time, $r(38) = -.37$, $p = .02$, two-tailed test, whereas no significant correlation was observed in the low math anxious group, $r(38) = -.26$, $p = .11$, two-tailed test. However, the difference in size of the correlations was not significant, $z(78) = -0.53$, $p = .26$, one-tailed test.

4. Discussion

This study tested the effects of math anxiety on arithmetic performance under endogenous (time limit) and exogenous (presence of a clock) time pressure. Overall, participants took longer and made more errors on problems that required a carry operation. As predicted, there was a significant main effect of math anxiety on response time, although no significant interactions were observed. Whilst there was no significant main effect of math anxiety on error rate, the hypotheses were partially supported. Interactions were observed for problems that involved a carry operation, whereby high math anxious individuals made significantly more errors (mean diff. > 3) when performing under a time limit. No difference was observed in the low math anxious group. There was no significant three-way interaction between math anxiety, time pressure and presence of a clock, however, there was a significant two-way interaction between math anxiety and presence of a clock: high math anxious individuals performed equally poorly with or without the presence of a clock, whereas the number of errors in the low math anxious group was significantly higher when a clock was present, producing almost the same number of errors as the high anxious group.

We hypothesised that time pressure would negatively impact performance in the high math anxious group and that the presence of a clock would compound this. Justification for this stemmed from the concept that a time limit would induce negative internal dialogue, i.e. intrusive thoughts, among those high in math anxiety, but a constant visual reminder of the time would exacerbate this effect. However, it seems that a time limit alone was sufficient to detrimentally affect performance in the high math anxious group. Importantly, this was the case only on problems requiring a carry operation. These findings are consistent with previous studies of the online effects of math anxiety, which have found math anxiety to be inversely related to performance on problems that rely heavily on working memory resources (Ashcraft & Kirk, 2001; Faust et al., 1996). The current findings demonstrated a large effect (d = 0.98) of math anxiety on error rate when participants were given a time limit, to the extent that, in the high math anxious group, the mean number of errors under time pressure was approximately four times the number under no pressure. In real world test scenarios such a difference could have notable implications for a student's grade.

Interestingly, whilst the presence of a clock did not add to a performance deficit among high math anxious individuals, it did adversely affect the low math anxious group, demonstrating a large effect size (d = 1.72). When no clock was visible the low math anxious group averaged almost no errors on problems involving a carry operation. However, the number of errors rose to a rate equivalent to that of the high math anxious group when a clock was present. This result was unexpected and a replication study would be useful. Nonetheless, this finding has important implications for testing, whereby a constant visual reminder of the time may negatively impact performance even among individuals who do not self-report as being math anxious.

We posit that time pressure may negatively impact individuals by acting as a secondary task, using valuable working memory resources. However, the mechanisms underpinning this may vary depending on the endogenous or exogenous nature of the time pressure. A time limit itself has no concrete presence; without regular reminders it is down to the individual to keep track of the time remaining in a given task. Such time keeping may consume the same working memory resources that are required for arithmetic involving keeping track of a carry operation, namely the central executive (Imbo, Vandierendonck & De Rammelaere, 2007). Coupled with endogenous distractors in the form of intrusive thoughts about time pressure, it is possible that working memory resources are seriously depleted among high math anxious individuals when performing arithmetic involving carry operations with a time limit. Contrary to what was hypothesised, the presence of a clock did not exacerbate math anxiety effects under time pressure; we tentatively propose that, for the high math anxious group, the presence of a clock may have actually counteracted the effect of performing under a time limit. That is, the constant visual reminder of the time may have minimised the need to keep track of it, thus freeing up valuable working memory resources. Of course, such suggestions are somewhat speculative and further research is needed. Relatedly, externalising endogenous distractors (intrusive thoughts) has been shown to enhance arithmetic performance. For example, Park, Ramirez and Beilock (2014) asked high math anxious children to write down their thoughts and feelings about an upcoming exam and results showed a significant drop in differential performance between low and high math anxious groups. Also, DeCaro et al (2010) asked participants to talk aloud during arithmetic problem solving and to focus on the calculation steps. They found that talking aloud helped minimise pressure-induced worries and improved performance. Together, these findings suggest that keeping intrusive thoughts at bay and taking a more goal-directed approach of focusing on the task at hand may alleviate performance pressure on arithmetic problem solving.

The present study is limited in its ability to fully explain the mechanisms that underpin the observed effect of math anxiety on performance under time pressure, but it is feasible that math anxiety is related to avoidance motivation, in which a speed-accuracy trade-off takes place. Here we found a significant negative correlation between error rate and response time to carry problems only among high math anxious individuals; no significant correlation was observed in the high math anxious group. Thus, previous findings that have demonstrated a link between avoidance motivation and performance under time pressure (Roskes et al., 2013) might hold particular importance in the study of math anxiety, especially concerning the role of intrusive thoughts.

Whilst previous studies have demonstrated a link between intrusive thoughts and math anxiety (Hunsley, 1987; Hunt et al., 2014), future work on the effect of time pressure would benefit from incorporating measures of self-reported intrusive thoughts. Similarly, further research should include measures of avoidance and approach motivation. In addition, the way in which time pressure can be introduced is varied and further work could be done to assess performance in a range and combination of conditions, such as varying the frequency of reminders of time remaining, including verbal and visual techniques. Also, more can be done to increase the ecological validity of the testing scenario, for example, testing could take place in an exam hall with others present.

In sum, the present study found strong evidence to suggest the nature of time pressure needs to be considered when studying the effects of math anxiety on arithmetic performance.

Endogenous time pressure (time limit) adversely affected performance among high math anxious individuals, whereas exogenous time pressure (presence of a clock) affected performance among low math anxious individuals. The current findings may have important implications for test situations, whereby the implementation of a time limit or presenting a clock in view of individuals may affect their math performance. Educators and examiners may need to take this into account when designing assessments.

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