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Does maths anxiety make people bad decision-makers? The link between mathematical anxiety and cognitive reflection

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Abstract

When asked to solve mathematical problems, some people experience anxiety and threat, which can lead to impaired maths performance. The present studies investigated the link between maths anxiety and performance on the cognitive reflection test (CRT). The CRT is a measure of a person's ability to resist intuitive response tendencies, and it correlates strongly with important real-life outcomes, such as time preferences, risk-taking, and rational thinking. Experiment 1 demonstrated that mathematical anxiety was a significant predictor of cognitive reflection, even after controlling for the effects of mathematical knowledge and test anxiety. In Experiment 2 both working memory load and mathematical anxiety were associated with lower levels of cognitive reflection. A potential explanation is that maths anxiety is linked to lower levels of cognitive reflection, because anxious thoughts burden working memory resources. Given earlier findings that showed a close link between cognitive reflection, unbiased decisions and rationality, our results suggest that mathematical anxiety might be negatively related to individuals' ability to make advantageous choices and good decisions.

Keywords: cognitive reflection test; decision making; dual-task manipulation; heuristics and biases; mathematical anxiety; numeracy; rationality; test anxiety; working memory.

The feeling of tension, apprehension and fear that some people experience when they have to deal with maths content has been termed mathematical anxiety (Ashcraft, 2002). Maths anxiety interferes with maths performance and it leads to negative maths-related attitudes and self-perceptions, an avoidance of elective maths courses, and it also affects people's career opportunities and career choices (Hembree, 1990). Whereas the negative consequences of maths anxiety on educational outcomes are well-documented, it is less clear whether maths anxiety also affects people's behaviour in other contexts.

This question is particularly interesting, given the well-known effects of numeracy levels on an individual's real-life functioning. Indeed, low numeracy is associated with reduced economic productivity (Williams, Clements, Oleinikova & Tarvin, 2003), higher rates of unemployment, mental and physical illness, as well as higher rates of arrest and incarceration (Gross, Hudson & Price, 2009). Low numeracy is also associated with impaired risk comprehension, and it leads to biases in judgment and decision making (see Gigerenzer, Gaissmaier, Kurz-Milcke et al., 2008; Reyna, Nelson, Han & Dieckmann, 2009 for reviews). Although meta-analyses suggested correlations of around -.30 between maths performance and maths anxiety (e.g., Hembree, 1990), maths anxiety is not always paired with low levels of numeracy (cf., Ashcraft & Krause, 2007). Thus, it is of interest, whether maths anxiety is associated with impaired decision-making skills, when the effects of numeracy are controlled for.

Lab-based investigations have revealed the cognitive mechanisms underpinning the negative effects of maths anxiety. When solving arithmetical problems, participants with high maths anxiety have higher error rates, especially in the case of complex problems (e.g., Faust, Ashcraft, & Fleck, 1996). Participants with high maths anxiety also often show a characteristic pattern of responding quickly to problems, displaying a "local avoidance" of the uncomfortable test situation (cf., Faust et al., 1996), and probably decreasing their chances of generating correct responses. Studies have also indicated that maths anxiety has an online effect on maths performance through hampering working memory resources (Ashcraft & Kirk, 2001; Mattarella-Micke, Mateo, Kozak et al., 2011).

The aim of the following studies was to explore the link between mathematical anxiety and individuals' decision-making abilities. Our indicator of decision-making skills was the Cognitive Reflection Test (CRT; Frederick, 2005), which is a short test measuring a person's tendency to override an intuitively compelling response, and to engage in further reflection which can lead to a correct solution. As an example, consider the following item:

A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost? _____ cents.

Although the correct response is 5 cents, many participants give the response "10 cents", which seems to pop into mind effortlessly. Cognitive reflection involves the ability to effectively monitor and correct such impulsive response tendencies.

Cognitive reflection was found to be negatively related to temporal discounting (i.e., the tendency to prefer smaller, immediately available rewards over larger rewards which will be available later), and positively related to choosing gambles with higher expected values (Frederick, 2005). Further studies showed that the CRT was also related to some typical heuristics and biases (e.g., Liberali, Reyna, Furlan et al., 2012; Toplak, West & Stanovich, 2011). Notably, some of these tasks (e.g., syllogistic reasoning problems) contained no numerical information. Furthermore, although the CRT correlates with measures of intelligence and numeracy (e.g., Frederick, 2005) it was found to explain additional variance in reasoning and decision-making tasks when it was administered together with measures of intelligence and numeracy (Liberali et al., 2012; Toplak et al., 2011). Overall, these results demonstrate that the CRT is a very powerful predictor of a person's ability to make unbiased judgments and rational decisions on a variety of tasks.

In the studies that we report below we tested the hypothesis that maths anxiety might be related to performance on the CRT. We based this prediction on the observation that maths anxiety leads to a tendency to generate and accept responses quickly, without taking the opportunity to correct mistakes (cf., Faust et al., 1996). In other words, it seems that maths anxiety reduces cognitive reflection.

In summary, in the following studies, we tested the prediction that maths anxiety is linked to relatively poor performance on the CRT. In Experiment 1 we tested this hypothesis while we controlled for the effects of maths knowledge and test anxiety. Experiment 2 investigated a potential mechanism underlying this relationship.

Experiment 1

In Experiment 1 we tested the prediction that maths anxiety is negatively associated with cognitive reflection. Building on earlier claims that the CRT is "not just another numeracy scale" (cf., Liberali et al, 2012; p.361), but also a potent indicator of a person's general ability to avoid tempting, easy-to-generate heuristic responses, we expected that the negative relationship between maths anxiety and the CRT will be present, even when we control for the effects of a person's general mathematics knowledge.

Specifically, we tested a path model in which mathematical anxiety is directly related to poor performance on the CRT. Additionally, we hypothesized an indirect link between maths anxiety and cognitive reflection through general mathematics knowledge. Finally, we also tested the potential effect of test anxiety on these links. We wanted to control for the effects of test anxiety (see also Devine, Fawcett, Szucs & Dowker, 2012), as maths anxiety and test anxiety show moderate correlations, and it has been argued that maths anxiety could be just a form of test anxiety (Richardson & Woolfolk, 1980).

Method

Participants The participants were 405 psychology students (M_{age}= 20.3; *SD* = 3.1; range 18 to 53 years; 81% females) from the University of Florence, Italy.

Materials *Cognitive reflection test* (CRT; Frederick, 2005): The CRT is a three-item test which consists of word problems including numerical information (see an example above). A composite score was calculated, based on the sum of correct responses.

Mathematics Prerequisites for Psychometrics (MPP; Galli, Chiesi, & Primi, 2011): This test measures the mathematics skills needed by students enrolling in introductory statistics courses. The test consists of 30 multiple-choice problems. Cronbach's alpha was .80.

Abbreviated Maths Anxiety Scale (*AMAS*, Hopko, Mahadevan, Bare & Hunt, 2003; see details on the Italian adaptation in Primi, Busdraghi, Tomasetto et al., *in submission*). This 9-item scale measures maths anxiety experienced by students in learning and test situations. Participants have to respond on the basis of how anxious they would feel during the events specified, using a 5-point response scale. Cronbach's alpha was .87.

Test Anxiety Inventory (TAI, Spielberger, 1977). The scale contains 20 items designed to measure anxiety associated with test-taking situations. Participants have to respond on the basis of how they would generally feel during the events specified using a 4-point response scale. In our sample, Cronbach's alpha was .93.

Procedure The scales were presented in a paper-and-pencil format, and students worked through the tasks individually. The order of presentation was: MPP, TAI, AMAS and CRT. Participants were informed that participation was voluntary and anonymous, and they were asked to give written informed consent. The average administration time was 50 minutes.

Results

Table 1 presents the descriptive statistics for our measures, and the correlations between them. As expected, maths anxiety and maths knowledge were both significantly correlated with the CRT, and maths anxiety was also significantly correlated with maths knowledge. Finally, maths anxiety was also related to test anxiety.

To further understand the mechanism underlying the relationships between these variables, we tested the hypothesis that maths knowledge mediates the effect of maths anxiety on cognitive reflection. Recently, researchers (e.g., Hayes, 2009) have recommended the use of the bootstrapping procedure over the Sobel test in assessing indirect effects of mediation models, as the bootstrapping procedure does not impose the assumption of normality of the sampling distribution on indirect effects. In our study, the mediation hypothesis was tested with SPSS macro (the INDIRECT procedure) for bootstrapping (with 5000 bootstrap samples) to estimate 95% confidence interval (95 CI) (for more details see Preacher & Hayes, 2008).

Table 1: Correlations between the CRT, maths knowledge, maths and test anxiety, and descriptive statistics for each measure (**p<.01; ***p<.001)

	1	2	3	4
1. CRT	--			
2.Maths knowledge	.47***	--		
3.Maths anxiety	-23***	-.17**	--	
4. Test anxiety	-.09	-.08	.54***	--
M	1.02	22.9	23.4	42.04
SD	.99	4.6	6.6	11.8

We estimated the indirect effect of maths anxiety on cognitive reflection, quantified as the product of the Ordinary Least Squares (OLS) regression coefficient estimating maths knowledge from maths anxiety (path *a* in Figure 1), and the OLS regression coefficient estimating cognitive reflection from maths knowledge controlling for math anxiety (path *b* in Figure 1). A bias-corrected bootstrap-confidence interval (CI) for the product of these paths that does not include zero provides evidence of a significant indirect effect of maths anxiety on cognitive reflection through maths knowledge (Preacher & Hayes, 2008). The INDIRECT procedure revealed a significant indirect effect of maths anxiety on cognitive reflection through maths knowledge (point estimate = -0.01, 95% *CI*= -0.02 to - 0.004). Kappa squared was 0.079 (95% CI = 0.026, to 0.132) indicating a medium effect size for the indirect effect (Preacher & Kelly, 2011). Figure 1 also shows the significant parameter associated with path *c'*, which indicates a direct effect of maths anxiety on the CRT.

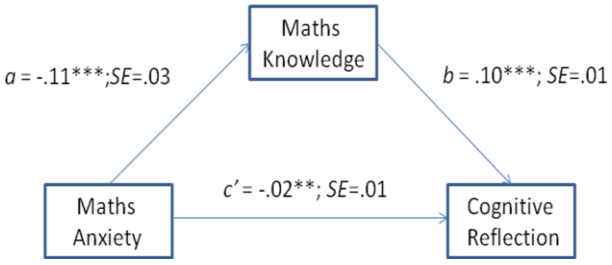

Figure 1: Path model depicting the relationships between maths anxiety, maths knowledge, and cognitive reflection (a, b, c' are unstandardized OLS regression coefficients;**p<.01; ***p<.001).

In sum, the results show that, once the effect of maths knowledge on cognitive reflection was controlled for, the effect of maths anxiety on cognitive reflection was still significant. Overall, the results indicate that the effect of maths anxiety on the CRT was partially mediated by mathematical knowledge, but even when this effect was controlled for, there was a direct effect of maths anxiety on the CRT. To investigate whether these effects were affected by test anxiety we included test anxiety as covariate in the mediation model simultaneously with the other predictor variables. Controlling for the effect of test anxiety did not substantially change the relationships between maths anxiety, maths knowledge and the CRT, and the effect of test anxiety was not significant (p=.46).

Discussion

In Experiment 1 we tested the prediction that maths anxiety is associated with reduced cognitive reflection, and that this relationship is present even when the potential indirect link between maths anxiety and cognitive reflection through maths knowledge is controlled for. We expected this on the basis of earlier findings which showed that maths anxiety leads to a tendency to impulsively accept incorrect responses, without much reflection (cf., Faust et al., 1996). We also tested the potential effects of test anxiety on the links between maths anxiety, maths knowledge and cognitive reflection.

The results confirmed our predictions. Specifically, we have found both a direct link between maths anxiety and cognitive reflection, and an indirect link through maths knowledge. These results have several implications. One is that maths anxiety is not only linked to impaired performance in arithmetical problems which are presented in the form of numbers and symbols, but in word problems with numerical content. To the best of our knowledge, our study was the first to test the link between maths anxiety and the ability to solve maths word problems. Nevertheless, our aim was not simply to demonstrate this link. Indeed, the CRT is considered to be more than just a maths task (cf. Liberali et al., 2012). We expected, and found, that the link between maths anxiety and cognitive reflection was not simply the consequence of lower numeracy levels, or a reduced ability to apply maths knowledge in highly maths anxious individuals. Indeed, when we controlled for the effect of maths knowledge, the link between maths anxiety and the CRT was still significant. Overall, our results suggest that maths anxiety is linked to maths performance in two ways: directly, and through an association with reduced maths knowledge.

Whereas these results clearly demonstrate that there is an association between maths anxiety and cognitive reflection, the causal link between these constructs is unclear. We hypothesized that maths anxiety led to a reduction in cognitive reflection. Nevertheless, in theory, it is also possible that reduced cognitive reflection leads to increased maths anxiety. Thus, one aim of Experiment 2 was to better understand the link between maths anxiety and cognitive reflection.

Ashcraft and Kirk (2001) demonstrated that the effects of maths anxiety arose from the burden that anxious thoughts imposed on working memory (WM). Other lines of research (e.g., De Neys, 2006) demonstrated that in the case of tasks which involved a conflict between a heuristic and a normatively correct response, employing a WM load decreased normative performance, and increased participants' tendency to give a heuristic response. Given

that the CRT problems involve a heuristic-normative conflict, we expected that a WM load will lead to a reduction in normative responding. That is, anxiety and WM load affect cognitive reflection in a similar way.

Experiment 2

In Experiment 2, we adopted a procedure which was previously used by De Neys (2006). In this study, participants had to memorize either simple or complex dot patterns (i.e., they were allocated into either a low- or a high WM-load condition) or they performed the task without a cognitive load. Additionally, they were asked to solve problems with a conflict between a tempting heuristic response and a normative response.

Based on the idea that anxious thoughts burden WM resources, we hypothesized that WM load and anxiety will affect reasoning performance in a similar way (i.e., they will be linked to performance decrements on the CRT).

Besides their relationship with reasoning accuracy, we were also interested in the link between WM-load and maths anxiety and reaction times on the CRT, as well as self-reported anxiety while participants completed the tasks. The purpose of including these additional measures was to better understand the mechanisms through which anxiety and working memory load might affect cognitive reflection. Whereas there are good reasons to expect that anxious participants will rush through the tasks (e.g., Faust et al., 1996), and report higher levels of anxiety while solving the CRT problems, WM-load in itself might not lead to these consequences. In addition, including a measure of anxiety that participants experienced while they worked through the problems made it possible to assess the ecological validity of the AMAS with regard to solving the CRT problems.

Finally, it seems plausible that the negative relationship between mathematical anxiety and cognitive reflection arose in Experiment 1 because maths anxiety reduced cognitive reflection. Nevertheless, in theory, it is also possible that reduced cognitive reflection leads to increased maths anxiety. If this was the case, the WM-load manipulation (which is expected to reduce cognitive reflection) should lead to an increase in participants' levels of anxiety while they are working through the tasks.

In summary, we expected that maths anxiety would be negatively related to cognitive reflection, and to the time that participants spend on solving the problems. By contrast, we expected that WM-load would not result in decreased reaction times, and would not lead to higher levels of anxiety.

Method

Participants Eighty-nine psychology students from a UK university participated in the study (66 females; M_{age}= 22 years 4 months; *SD* = 8.11; range: 18-56 years). The participants were either offered ungraded course credit or a small payment for participation. Participants were randomly allocated to the control, low load or high load condition.

Materials Maths anxiety was assessed by the AMAS (Cronbach's alpha: .92). Participants were also administered the CRT, but instead of generating a response, participants had to select from three options: the correct response, the typical heuristic response and an atypical response. We administered the CRT in this format in order to avoid a potential floor effect, given that, even without a secondary load, performance tends to be low.

The *secondary task* was the Dot Memory Task (DMT), a classic spatial storage task previously used by De Neys (2006) and Gillard et al. (2009). A 3x3 matrix, filled with three (low-load condition) or four dots (high-load condition) was presented. Participants had as much time as they needed to memorize the pattern. Then they solved a CRT problem, and they had to recall the dot pattern afterwards. Participants in the control condition worked through the CRT problems without distraction.

Procedure The AMAS was presented in a paper-and-pencil format. The CRT was presented on the computer, together with the DMT. Participants solved a practice problem before working through the test problems. For the CRT, both accuracy and reaction times were recorded. Immediately after completing the CRT, participants were asked to report the level of anxiety that they experienced while working through the problems on a 10-point scale. The average testing time was 35 minutes (participants also solved some other problems which are not reported here).

Results

Accuracy on the DMT was high in both the low- (91%) and high-load (93%) conditions. The proportion of atypical responses on the CRT task was extremely low (3%), indicating that participants primarily selected the heuristic and correct responses. As a preliminary step for our main analyses, we created high and low maths anxiety groups by performing a median split, with participants with an AMAS score of 20 or below included in the low anxiety group (*n*=46).

Table 2: Average performance on the CRT in low and high maths anxiety participants across the WM-load conditions (*SD*s are displayed in brackets).

	Low anxiety	High anxiety	Total
Control	1.60 *(1.17)*	.90 *(1.00)*	1.13 *(1.09)*
Low load	1.00 *(1.25)*	.29 *(.61)*	.66 *(1.04)*
High load	.62 *(1.02)*	.63 *(.92)*	.62 *(.98)*
Total	.96 *(1.17)*	.65 *(.90)*	.81 *(1.05)*

The purpose of our first analysis was to test the effects of cognitive load and mathematical anxiety on cognitive reflection (see Table 2 for descriptive statistics). A 2x3 ANOVA with maths anxiety group (high/low) and WM load (high/low/none) as between-subjects factors indicated a significant effect of maths anxiety ($F(1,88)=4.15$,

p=.045, η_p^2=.05), and a significant effect of WM load (F(2,88)=3.30, p=.042, η_p^2=.07). There was no interaction between maths anxiety and cognitive load (p=.37).

Our next analysis investigated the effects of maths anxiety and WM load on reaction times on the CRT. A 2x3 ANOVA with maths anxiety group (high/low) and WM load (high/low/none) conditions indicated a significant effect of maths anxiety (F(1,88)=4.57, p=.036, η_p^2=.05), but no effect of WM load (p=.27), and no interaction (p=.27). Participants with low anxiety spent on average 22.29 seconds (SD=16.10), whereas highly anxious participants spent 15.31 seconds (SD=7.31) on each problem.

We also checked the effects of maths anxiety and WM load on self-reported anxiety levels. This was important in establishing the ecological validity of the AMAS in relation to the CRT. A 2x3 ANOVA with maths anxiety group (high/low) and WM load (high/low/none) conditions indicated a significant effect of maths anxiety (F(1,88)=37.18, p<.001, η_p^2=.53), but no significant effect of WM load (p=.53), and no interaction (p=.85). Highly anxious participants' average self-reported anxiety level was 4.91 (SD=2.19) on a 10-point scale, while the average rating of participants with low AMAS scores was 2.52 (SD=1.36). There was a strong correlation between participants' self-reported anxiety and their AMAS scores (r(86)=.56, p<.001).

Discussion

In line with our hypotheses, Experiment 2 demonstrated that both anxiety and WM load were associated with poor performance on the CRT. This result support earlier claims that anxious thoughts regarding mathematical content act in a similar way as WM-load (Ashcraft & Kirk, 2001; Mattarella-Micke et al., 2011). At the same time, our results also demonstrate that the effects of maths anxiety do not simply arise through hampering WM resources. Indeed, in contrast with maths anxiety, WM load did not lead to reduced response times.

Another interesting finding is that although WM load reduced cognitive reflection, it did not lead to increased levels of self-reported anxiety. This suggests that whereas increased anxiety might reduce cognitive reflection, a manipulation of cognitive reflection does not affect anxiety levels. This supports our hypothesis regarding the causal link between maths anxiety and cognitive reflection.

Finally, the fact that self-reported anxiety levels correlated strongly with AMAS scores confirms the ecological validity of the AMAS in predicting anxiety levels elicited by word problems including numerical content, which were presented in a low-stakes situation.

General discussion

In two experiments we tested the hypothesis that maths anxiety is linked to reduced cognitive reflection. As expected, we found that students with high maths anxiety performed worse on the CRT than students with low levels of anxiety. This effect was still present when we controlled for participants' maths knowledge and test anxiety (in Experiment 1). Experiment 2 also shed light on some of the mechanisms behind this effect.

Specifically, in line with Ashcraft and Kirk (2001) and Mattarella-Micke et al. (2011), we demonstrated that maths anxiety was associated with performance decrements, which were similar to the effect of WM load. To the best of our knowledge, our Experiment 2 is the only one, apart from Ashcraft and Kirk (2001), to demonstrate this through a dual-task manipulation, and it is the first one, which demonstrates this in the case of word problems including numbers. Additionally, Experiment 2 also showed that mathematical anxiety was related to a tendency to rush through problems (see also Faust et al., 1996). However, this effect did not arise as the result of hampered working memory resources.

These findings have several important implications. First, our results demonstrate that maths anxiety arises, and affects performance in low-stakes situations, and in the case of word problems including numbers. Second, we showed that maths anxiety was linked to cognitive reflection in two different ways. Indeed Experiment 1 demonstrated a mediating role of general maths knowledge between maths anxiety and cognitive reflection. Additionally, maths anxiety was directly linked to participants' ability to reflect on their own performance, and to detect and correct their own errors (as proposed by Faust et al., 1996; and indicated by the direct link between maths anxiety and cognitive reflection). Experiment 2 suggested that this link between anxiety and performance on the CRT could have been the result of the reduced availability of cognitive resources in anxious participants, and/or the shorter time they spent on the problems.

As we described in the introduction, the CRT is considered to be more than just a numeracy test (cf., Liberali et al., 2012). Indeed, it correlates highly with tasks measuring risky decision-making, future discounting, and rational thinking (Frederick, 2005; Liberali et al., 2012; Toplak et al., 2011). Much research shows the negative effects of low numeracy on judgement and decision making (Gigerenzer et al., 2006; Reyna et al., 2009), as well as on employability, mental and physical health, and criminal behaviour (e.g., Gross et al., 2009). The relationship between maths anxiety and cognitive reflection that we demonstrated in our studies suggests that the negative effects of maths anxiety might also extend to individuals' decision making skills. In fact, it is likely that maths anxiety affects individuals' economic behaviour, as well as their understanding of risks. Thus, researchers of judgment and decision making should take into account maths anxiety as a potential source of individual differences in decision making.

Finally, our results are also relevant for researchers of decision making and reasoning in terms of our understanding of what cognitive reflection is. The CRT is

an extremely popular measure, as it only takes a few minutes to administer, and, at the same time, it is one of the best predictors of rational thinking and decision-making skills. Nevertheless, our findings clearly show that rather than simply measuring a metacognitive trait, the CRT also has a significant mathematics component. Indeed, it is not only related to a person's maths ability, but also to their levels of maths anxiety. Thus, our findings call for the urgent need for researchers to better understand the cognitive bases of "cognitive reflection", and the tendency for people to jump into conclusions without a second thought.

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