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MATHS ANXIETY DOES NOT MODERATE THE LINK BETWEEN SPATIAL AND MATHS ABILITY

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Abstract

Spatial ability (SA) is known to be closely related to mathematical ability (Tosto et al., 2014). Maths anxiety (MA) has been shown to affect both mathematical and spatial ability (Maloney, 2011). The present study investigated the relationship between maths performance and spatial ability, as well as the effects of MA and gender on the association between them. General cognitive ability and trait anxiety were added as control variables. Data were collected from 146 twins (32% males) aged 17-33. Maths performance was measured with Problem Verification Task (PVT). SA was measured with Mental rotation task. MA was measured with sMARS questionnaire. General cognitive ability was measured with Raven's matrices. Trait anxiety was measured with Spielberger anxiety rating scale. There were no correlations between SA and maths performance, except a negative correlation between SA and PVT reaction time variance. MA did not moderate the association between SA and maths performance. Interestingly, the interaction term between trait anxiety and SA was significant as a predictor for PVT reaction time. Posthoc analysis showed that higher spatial ability was associated with lower reaction time in PVT for high trait anxiety individuals only. Neither main effects of gender and maths anxiety, nor the interaction term between them were significant while predicting spatial ability. Altogether, our results indicate that the interplay between anxiety and mathematical cognition is complex and requires further research.

Keywords: Maths anxiety, maths performance, spatial ability, education, academic anxiety.

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1. Introduction

STEM (Science, Technology, Engineering and Mathematics) play an important role in modern society. Individual differences in cognitive abilities, especially mathematical and spatial abilities, have been identified as factors that predict success in STEM careers (Wai, et al., 2009). Research has shown moderate correlations between mathematical and spatial abilities (Thompson, Detterman & Plomin, 1991; Hegarty & Kozhevnikov, 1999; Assel, Landry, Swank, Smith, & Steelman, 2003; Rotzer, et al., 2009; Szucs, et al., 2013; Tosto et al., 2014). For example, a correlation of ~.5 was found in a study investigating a link between spatial and maths ability at different grades: kindergarten: r = .45; third grade: r = .49; sixth grade: r = .54 (Mix et al., 2016). Research also suggested that these abilities rely on partially overlapping neural networks (Hubbard, Piazza, Pinel & Dehaene, 2005).

Spatial abilities are considered to be a moderate predictor for mathematical performance, which is shown by longitudinal studies. For example, one study showed that children's spatial skill at age 5 predicted their performance on an approximate symbolic calculation task at age 8 (R-squared = 0.48 and that this relation was mediated by children's linear number line knowledge at age 6 (Gunderson, et al., 2012).

Studies demonstrated that mathematical performance is susceptible to the influence of emotional factors, with mathematics anxiety (MA) playing a particularly important role (Dowker, Sarkar & Looi, 2016). MA has been defined by Richardson and Suinn as "a feeling of tension and anxiety that interferes with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic situations" (Richardson & Suinn, 1972, p. 551). MA correlates with performance, academic achievement, avoidance behavior in maths-related situations and even life-choices such as education subjects and career destinations (for review see Artemenko, Daroczy & Nuerk, 2015; Suárez-Pellicioni, Núñez-Peña, & Colomé, 2016).

Negative consequences of high maths anxiety (HMA) are mainly interpreted in the framework of Attentional control theory (ACT: Eysenck, et al., 2007). According to ACT, people with HMA have increased sensitivity to the stimuli, which are irrelevant to the tasks, which in turn results in performance impairment. However, to date, little research has addressed the exact nature of this "increased sensitivity". A recent study showed (Suárez-Pellicioni, Núñez-Peña, and Colomé, 2013) that people with HMA have an increased reactivity to the errors made with ERP technique. However, this sensitivity might also be studied without using neuroimaging methods, with the help of mental noise measure, suggested by Robinson and Tamir (2005). In this case, an increased sensitivity towards irrelevant stimuli in HMA people, suggested by ACT, may result in instability in performance, manifested in higher variance of the reaction time in math-related task. We hypothesized that mental noise correlates positively with maths anxiety.

Previous research assumed that people with HMA suffered from reduced WM capacity during task performance as a result of anxiety-driven ruminations (Ashcraft & Kirk, 2001). However, recent work by Maloney, Risko, Ansari, and collaborators (2010) suggests that MA could result from a basic low-level deficit in numerical processing that compromises the development of higher-level mathematical problem solving. According to Maloney and collaborators (2011) low-level deficit in numerical processing is rooted in the less precise representation of numerical magnitude. In this study they showed that

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individuals with HMA have less precise representations of numerical magnitude than their low maths anxiety (LMA) peers (Maloney, et al. 2011). Representation of numerical magnitude is mainly discussed in terms of Number line (see Gunderson, et al., 2012, for discussion) and found to be predicted by spatial ability. For example, Gunderson and colleagues (2012) showed longitudinally, that children's spatial skill (i.e., mental transformation ability) at the beginning of 1st and 2nd grades (age: Mean = 7.1, SD = 0.6) predicted linear number line knowledge over the course of the school year (R-squared = 0.14). Therefore, low spatial ability might be a cause for maths anxiety development. Recent studies have also confirmed this chain of reasoning by showing the association between spatial ability and MA (Maloney, 2011; Ferguson et al., 2015). For example, MA has been found to have a moderate negative correlation with performance on spatial tasks (~ -.5, e.g. Maloney, 2011). Moreover, a recent research showed that individuals with HMA perform worse on measures of small- and large-scale spatial skill (Ferguson et al., 2015). Therefore, spatial ability may contribute to the development of maths anxiety via its influence on such low level numerical processing and be reflected in number line task. We hypothesize that mathematics anxiety may moderate the association between higher level maths performance and spatial abilities.

MA is generally found to vary as a function of gender, with males showing less anxiety than females (Maloney et al., 2012; Ferguson, et al., 2015). For example, one study (Devine et al., 2012) showed that maths anxiety was 0.33 standard deviations higher in girls than in boys ($F(2,429) = 11.52$; $p = 0.0007$). Another study demonstrated higher maths anxiety in females (Cohen's d = .24) (Ferguson and collaborators, 2015). Gender differences are also consistently found in spatial abilities. For example, Ferguson and collaborators (2015) demonstrated higher scores on the measure of spatial ability (i.e. Santa Barbara Sense-of-Direction Scale (Hegarty et al., 2002) in males (Cohen's d = .34). Moreover, females had lower scores in large-scale (Cohen's d = .72) and small-scale spatial task (Cohen's d = .63). To sum up, both spatial ability and maths anxiety consistently show gender differences. We hypothesized that gender will moderate the link between maths anxiety and spatial ability.

Maths anxiety was also generally found to correlate with trait anxiety. For example, a meta-analysis (Hembree, 1990) of 151 studies found a mean correlation of 0.35 between the measure of maths and general anxiety. In addition, maths ability was associated with general cognitive abilities ($\eta 2 = .59$, Deary et al., 2007). Therefore, trait anxiety and general cognitive ability were used as control variables in the analysis.

2. Problem Statement

To conclude, the exact nature of the relationship between spatial ability and maths ability remains unclear. There are several factors that can play an important role in this relationship, among which maths anxiety and gender may have a substantial effect.

3. Research Questions

The research question of the present study is whether maths anxiety moderate the association between spatial ability and maths ability. We are also interested in the role of gender and individual differences in neural noise, manifested in higher variance of the reaction time in maths-related task.

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4. Purpose of the Study

There are 4 main aims of the present study. First, we want to replicate the association between maths anxiety and spatial ability. Second, we want to test whether gender moderates the association between spatial ability and maths performance. Third, we want to test whether maths anxiety moderates the association between spatial ability and maths performance. And, fourth, we want to test whether mental noise associates positively with maths anxiety.

5. Research Methods

5.1. Participants

Data were collected from 146 twins (32% males) aged 17-33 (M = 21.27, SD = 3.52), participants in the ongoing project «Genetically Informative Study into Brain Mechanisms Underlying Mathematical Ability» at Tomsk State University.

All participants had normal or corrected-to-normal vision and no history of head injury, neurological or psychiatric disorder. Participants gave written informed consent prior to the study, which was approved by The Ethics Committee for Interdisciplinary Research of Tomsk State University. The data was collected at two experimental sites: Tomsk State University (Tomsk, Russia) and Psychological Institute of Russian Academy of Education (Moscow, Russia). There were no significant differences between participants at two experimental sites in terms of age and gender ($p > 0.05$).

5.2. Measures

The following tasks were administered to all participants in the study.

5.2.1. Maths anxiety

Maths anxiety was measured with the Shortened Maths anxiety Rating Scale (sMARS; Alexander & Martray, 1989). This test measures maths anxiety by presenting 25 maths-related situations. Participants are to rate these situations on a 5-point Likert scale in regards to how much anxiety they experience in particular situations. The sMARS was adapted into Russian via a reverse translation procedure. 4 items were removed from the questionnaire based on their poor psychometric properties. Following previous research (Ashcraft & Moore, 2009), the total score of all remaining items (21) on the test was used as a singular measure of maths anxiety.

5.2.2 Trait anxiety

Trait anxiety was measured with Spielberger Trait Anxiety Questionnaire (Spielberger, 1983), adapted to Russian by Khanin (1976). The questionnaire measures the level of trait anxiety. The questionnaire consists of 20 questions about how anxious participants are in their usual life and rating their answers on a 4-point Likert Scale. The trait anxiety score was calculated as the total sum of all items.

5.2.3 General cognitive ability

General cognitive ability was measured with shortened Raven's matrices (Raven, Raven, & Court, 1998). The test consists of series of incomplete matrices. In each task participants should choose one of the 8 suggested variants to complete the pattern. Originally, the test comprises 6 sets – A, B, C, D, E, and F. Within each set, the 12 items progressively become more difficult. We used 4 sets C, D, E, and F. Sets C, D, and E contained 6 tasks each: 1^{st}, 3^{rd}, 5^{th}, 7^{th}, 9^{th}, and 11^{th} (tasks with even numbers were excluded) and set F contained 12 tasks. Thus, there were 30 tasks in total. Sets were presented in the following order: C -> D -> E -> F, where each set in turn became more difficult. Total sum of correct items was used as the measure of general cognitive ability.

5.2.4. Spatial ability

Spatial ability was measured with Mental rotation test (MRT; Vandenberg & Kuse, 1978), which assesses the ability to mentally rotate an image of a geometrical shape. The three-dimensional shape was presented on top of the screen. Two other shapes were presented on the bottom of the screen and varied in the degree of the rotation. Rotation of target shapes ranged from 15° to 345°. Participants were to judge which one of them matches the one on the top. A maximum of 181 trials were presented over 3 min, and scores were calculated by the total sum of correct answers given in 3 minutes. 7 training trials with feedback about the correct answers preceded the test. Feedback was shown only in the training session. As the time is limited, the test cannot be completed fully, therefore participants were to solve the tasks as fast as possible.

5.2.5. Maths performance

Maths performance was assessed with Problem-verification task (PVT), which was developed as a measure of calculation fluency (the efficiency with which one can evaluate the veracity of an arithmetic solution) (Rinne & Mazzocco, 2014). This test was adapted to Russian from Tosto and colleagues (2013). It includes 48 arithmetic problems, each presented with a single solution, half of the answers were correct and half were incorrect. Participants were asked to judge whether the solution is correct and to respond as quickly as possible. The instruction was given before the training session (2 items). We used accuracy (A), reaction time (RT) and variance of the reaction time as a performance measures in the study. Given that Mean RTs always correlate with RT SD, a simple linear regression that predicts RT standard deviations on the basis of RT means was performed. The resulted standardized residuals were used as a maths performance variable – mental noise (Robinson and Tamir, 2005).

5.3. Statistical analysis

To test whether maths anxiety moderates the association between spatial ability and maths performance, Ordinary least squares analysis (OLS) was used. Using OLS analysis on twin data may lead to biased estimates of model parameters (Atkins, 2005; Carlin et al., 2005). Outcome values within pairs of twins tend to be more similar than values between unrelated participants and, hence, they are not statistically independent (Carlin et al., 2005). In order to take into account the paired structure of data, we used multilevel regression analysis with maximum likelihood estimator. Some previous studies

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demonstrated that maximum likelihood approach provided reliable results in paired data (Atkins, 2005). All variables were transformed into Z-scores before including into models. At the first step results of cognitive tests (MRT, Raven's) and MA were included as predictors for each maths outcome (PVT A, RT and variance of RT) (Model 1). At the second step Trait anxiety was added as a predictor (Model 2). At the third step interaction term between MA and MRT was added to evaluate whether MA affect the link between MRT and maths outcomes (Model 3). At the fourth step interaction term between trait anxiety and MRT was added to evaluate whether TA affects the link between MRT and maths outcomes (Model 4). To study whether gender moderates the association between spatial ability and maths performance the interaction term between gender and maths anxiety, as well as main effects of them, were included in a regression model as predictors for spatial ability.

These analyses were performed with Stata 13. Simple slope analysis (Cohen, Cohen, West & Aiken, 2013) was performed as a posthoc test to interpret the direction of results.

6. Findings

6.1. Descriptive statistics and correlations

The correlations between MRT and PVT RT and PVT accuracy were insignificant (p > .05), however there was a moderate negative correlation between MRT and PVT RT variance, $r(146) = -.22$, $p< .05$. sMARS correlated moderately with Trait Anxiety, $r(146) = .33$, $p< .05$, as well as with PVT RT, r(146) = .22, $p< .05$, but not PVT accuracy or RT variance ($p> .05$). Descriptive statistics and correlations for other variables in the study are shown in Table 1.

Table 01. Results of correlational analysis and descriptive statistics

Variables	Mean	SD	Correlations						
			1	2	3	4	5	6	7
1. PVT	40.56	5.77	1						
2. PVT RT	3.31	0.8	-.16	1					
3. PVTRT Variance	0	1	.04	0	1				
4. MRT	32.87	8.92	-.08	-.14	-.22*	1			
5. Raven's	16.22	5.23	.24**	-.21*	.03	.04	1		
6. TA	18.74	4.04	-.03	.11	-.07	.01	.08	1	
7. MA	44.54	13.87	-0.17	.22*	-.09	-.09	-0.1	.33**	1

Note: TA, trait anxiety, MRT, Mental rotation task, Raven's, Raven's progressive matrices, PVT, Problem verification task, MA, maths anxiety. Significant at p<.05 level: *p<.05, **p<.01.

6.2. Gender as a moderator between maths anxiety and spatial ability

Regression analysis was performed to test main effects and interaction between gender and maths anxiety in their effect on spatial ability. Neither the main effect of maths anxiety, nor the main effect of gender was significant for spatial ability performance (p>.05). The interaction term between MA and gender was also non significant (See Table 2).

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Table 02. Regression of Gender, Maths anxiety and Raven's score on Spatial ability

	B	SE	z	p-value	95% CI
Gender	.18	.21	.90	.37	-.22; .59
MA	-.16	.10	-1.58	.11	-.37; .04
Gender*MA	.31	.20	1.49	.14	-.10; .71
Raven's	.02	.09	.19	.85	-.16; .19
Loglikelihood	-171.69				
Between group variance	.12				
Within-group variance	.79				
R-squared (between group)	.03				
R-squared (within group)	.01				

Note: Raven's, Raven's progressive matrices, maths anxiety. B, Unstandardized beta, SE, standard error, z, z-test, CI, Confidence intervals. Significant at $p<.05$

6.3. Maths anxiety as a moderator between spatial ability and maths performance.

This analysis was conducted in several steps. In the first step, the effect of the MRT and MA on PVT performance was analyzed (see Table 3, Step 1). We also included Raven's scores to control for general cognitive ability effects. Analysis showed that PVT accuracy was predicted by Raven's scores only (B = .20, z = 2.59, p = .01). However, spatial ability was a significant predictor of PVT RT variance (B = -.23, z = 2.57, p = .01). There was no association between maths performance and maths anxiety.

In the second step, trait anxiety was added into the model as a predictor for each outcome. The analysis indicated that trait anxiety was not a significant predictor for any outcome variables when accounting for MRT and Raven's scores (see Table 3, Step 2). Effects of spatial ability and Raven's remained the same. In the third step, the interaction term between MRT and MA was added into the model (see Table 3, Step 3) to investigate whether MA moderated the association between MRT and maths performance. There were no significant associations between any of the outcomes.

In the fourth step, the interaction term between trait anxiety and mental rotation was added in the model as a predictor. Interestingly, the interaction term was significant (B = -.17, z = -2.42, p = .016) for PVT reaction time.

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Table 3. Results of hierarchical regression analysis

Steps	Predictors	Mathematical performance					
		PVT accuracy		PVT RT		PVT_variance	
Baseline model	Log likelihood	-150,31		-153,32		-177,064	
	Between group variance	0,31		0,52		0,11	
	Within-group variance	0,4		0,32		0,89	
	ICC	0,44		0,62		0,11	
Step 1		B	SE	B	SE	B	SE
	MRT	-.04	.07	-.09	.07	-.23*	.09
	Raven's	.20*	.08	-.05	.08	.03	.09
	MA	-.09	.07	.13	.07	-.12	.09
	Log likelihood	-146,18		-150,45		-173,24	
	Between group variance	0,25		0,46		0,1	
	Within-group variance	0,4		0,32		0,84	
	R-squared (between group)	0,11		0,08		0,06	
	R-squared (within group)	0,09		0,07		0,05	
Step 2		B	SE	B	SE	B	SE
	MRT	-.04	.07	-.09	.07	-.23*	.09
	Raven's	.20*	.08	-.05	.08	.04	.09
	MA	-.09	.07	.09	.07	-.10	.09
	TA	.01	.08	.12	.07	-.04	.09
	Log likelihood	-146,17		-149,29		-173,14	
	Between group variance	0,25		0,47		0,1	
	Within-group variance	0,4		0,31		0,84	
	R-squared (between group)	0,11		0,07		0,06	
	R-squared (within group)	0,09		0,07		0,05	
Step 3		B	SE	B	SE	B	SE
	MRT	-.05	.07	-.09	.07	-.21*	.09
	Raven's	.19*	.08	-.05	.08	.04	.09
	MA	-.09	.07	.09	.07	-.10	.09
	TA	.01	.08	.12	.07	-.04	.09
	Mental rotation * Maths anxiety	-.01	.07	-.01	.07	.05	.09
	Log likelihood	-146,14		-149,28		-172,95	
	Between group variance	0,25		0,47		0,1	
	Within-group variance	0,4		0,31		0,84	
	R-squared (between group)	0,11		0,07		0,06	
	R-squared (within group)	0,09		0,07		0,05	
Step 4		B	SE	B	SE	B	SE

MRT	-.04	.07	-.10	.07	-.22*	.09
Raven's	.20**	.07	-.06	.08	.05	.09
MA	-.10	.07	.10	.07	-.10	.09
TA	.02	.07	.08	.07	-.03	.09
MRT * TA	.06	.07	-.17*	.07	.13	.09
Log likelihood	-145,89		-146,45		-172,37	
Between group variance	0,24		0,47		0,05	
Within-group variance	0,4		0,28		0,87	
R-squared (between group)	0,12		0,09		0,11	
R-squared (within group)	0,09		0,1		0,08	

Note: TA, trait anxiety, MRT, Mental rotation task, Raven's, Raven's progressive matrices, PVT, Problem verification task, MA, maths anxiety. B, Unstandartised beta, SE, standard error. Significant at p<.05 level: *p<.05, **p<.01. Snijders & Bosker (1999) formula was used for between group R- squared.

6.4. Simple slope analysis for TA as a moderator between spatial ability and maths performance

To examine the association between MRT and PVT reaction time relationship at different levels of trait anxiety the **analysis of simple slopes** was performed (See Table 4). Conditional effect of MRT on PVT RT was estimated for three values of trait anxiety (mean +/- 1 s.d.) (see Figure 1).

Table 4. Results of simple slope analysis for interaction effect between trait anxiety and MRT on PVT RT

Trait anxiety	Effect of MRT				95% CI
	β	SE	z	*p*-value	
-1 s.d.	.06	.09	.70	.48	-.12; .24
Mean	-.10	.07	-1.51	.13	-.23; -.03
+1 s.d.	-.27	.10	-2.69	.00	-.46; -.07

Note: MRT, Mental rotation task. SE, standard error; β, standardized beta; p, significance level, Significant at p<.05 level

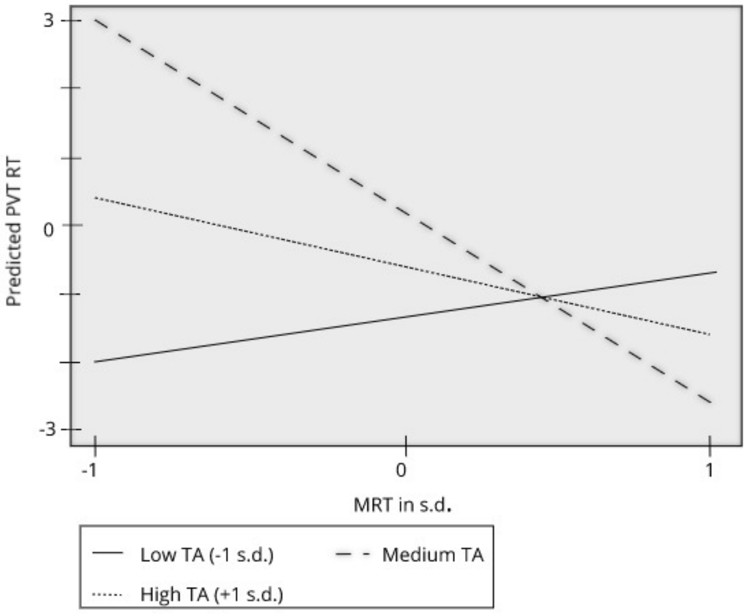

Figure 01. The effect of MRT on PVT RT for different levels of TA

7. Conclusion

Spatial ability is considered to be a good predictor for maths performance (Tosto et al., 2014). The present study found a negative correlation between mental rotation and PVT reaction time variance (mental noise), but not with PVT accuracy or reaction time. In other words, higher spatial ability was associated with higher stability of PVT reaction time. Our data suggest that MA affects stability of performance, rather than the quality of the performance. However, this finding needs further replication. The absence of an association between spatial ability and traditional measures of performance may be attributed to the ceiling effect in one of the measures: the PVT appeared to be an easy task and as a result, the variance in accuracy among participants could be too small to find the correlation. It has been previously shown, that maths anxiety can have different impact on tasks of different complexity level (Anxiety-complexity effect: Ashcraft & Faust, 1994; Faust, 1996; Ashcraft and Kirk, 2001; Suárez-Pellicioni et al., 2013), which might have affected the results.

Another factor, that may have played a role in the results of our correlation analysis, is the nature of the task used in this study to measure mathematics performance. The Problem Verification Task may not have a spatial component, which potentially explains the absence of the link with MRT. In addition, correlations may be weak due to an uneven development of abilities: while math ability will have been trained at school, the opportunity to improve spatial ability may have been limited or absent completely (Friedman, 1992). Spatial ability, specifically the ability to mentally rotate 3D objects, usually is not a part of a formal school or university education in Russia, while maths is an important part of curriculum, both in school and at university. Consequently, spatial ability might be undertrained in comparison with maths ability (especially arithmetic, which is primarily tested by PVT).

Contrary to previous research, no correlation has been observed between maths anxiety and spatial ability. Maloney (2011) argued that there is a link between MA and spatial ability and showed that HMA people performed significantly worse in paper-and-pencil mental rotation task than their LMA peers. The

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discrepancies in our findings might be driven by several issues. First, in the Maloney (2011) study the sample was divided into HMA and LMA groups, which may have inflated differences in spatial ability between them. In contrast, the present study used MA as a continuum, which takes into account the entire variability of the trait (Aiken & West, 1991). In addition, in the Maloney (2011) study, participants with scores under 20 constituted the LMA group, and participants with scores over 30 constituted the HMA group, while the mean for the full sample in the study was equal to 22.6. This places LMA group almost in the centre of the distribution, rather than bottom quartile of the overall distribution, as intended in the study by Maloney (2011).

Another possible source for the absence of a significant relationship between maths anxiety and spatial ability stems from the measures of maths anxiety used in different studies. We measured maths anxiety level with the sMARS questionnaire, which has been originally developed for schoolchildren or students. The questions in sMARS were designed with an assumption that participants meet maths-related tasks in their everyday educational environment. However, our sample consisted of adults, who had to recall their experience during education with a considerable delay. Although, sMARS was previously successfully used elsewhere for adults (Núñez-Peña et al., 2013), it may still affect the results of our study. While we refer to the deficit in low-level numerical representation as a main factor for the link between spatial ability and maths performance, our tasks do not test low-level maths ability directly, as suggested by Tosto and collaborators (2013).

The results showed no main effects of maths anxiety and gender on spatial ability, even after accounting for general cognitive ability effects (Rohde & Thompson, 2007; Maloney et al., 2012). The interaction term between them was also non significant as a predictor of spatial ability. Studies consistently show an effect of gender on spatial ability (Richardson, 1994; Jansen & Heil, 2010; Maloney, 2012; Ferguson, et al., 2015). However, several large-scale studies found only a very weak effect of gender. For example, gender accounted for less than 1 percent of variance in spatial ability (jigsaw puzzles and hidden shapes) in a large sample from Twins Early Development Study (Tosto et al., 2014). Similarly, another study of young adults from TEDS showed that gender explained only 4% in mental rotation task (Rimfield et al., 2017). Therefore, the absence of gender difference in mental rotation in our study might be a result of underpowered sample and overall small effect of gender on spatial ability.

We found a significant main effect of MA on PVT Reaction time, which is in line with the suggested negative effect of MA on performance (for review see Dowker et al., 2016). Only reaction time, not accuracy in the maths task was affected by maths anxiety, which again supports the idea that anxiety affects not the effectiveness of performance, but rather processing efficiency of the task (PET, Eysenck & Calvo, 1992). We found no main effects of either spatial ability, or maths anxiety for other maths performance outcomes. However, the interaction effect represents the combined effects of predictors on the dependent measure (Stevens, 1999). Contrary to our hypothesis, maths anxiety was not significant as a moderator between spatial ability and maths performance. Our findings provide no evidence that there is a direct link between spatial ability and maths performance, except for the association between spatial ability and variance of RT (Tosto et al., 2014). The overall association between spatial ability and maths performance them may be related to other cognitive and noncognitive

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variables, rather than maths anxiety. For example, one study showed that maths motivation plays an important role in the interplay between maths anxiety and maths performance (Wang et al., 2015).

Contrary to our hypothesis, maths anxiety did not correlate significantly with variance of reaction time in PVT, suggesting that MA isn't linked with stability of performance in maths-related tasks. As discussed above, both sMARS questionnaire and Problem verification task are subjected to a number of limitations, which might have led to the lack of the correlation. Variance of reaction time reflects self-regulation in the RT tasks and susceptible to automaticity, e.g. go/no go task (Robinson and Tamir, 2005). In contrast, PVT does not require regularity in cognitive operations, and as a result, variance in RT for this task might not be a good manifestation of mental noise.

Unexpectedly, the interaction term between trait anxiety and spatial ability as a predictor of mathematical performance was significant. There was a negative correlation between spatial ability and reaction time in PVT (high spatial ability increases the speed of performance) for high trait anxiety individuals, while there was no effect for those with low trait anxiety. High anxious individuals demonstrated a stronger link between spatial ability (e.g., MRT) and mathematical ability (e.g., PVT RT). These results are contrary to the Processing-efficiency theory (PET; Eysenck & Calvo, 1992) and Attentional control theory (Eysenck, et al., 2007), which suggest a negative effect of anxiety on performance (decrease in the speed of performance). Both theories view anxiety as interfering with and inhibiting performance. In contrast with these two theories, our results may be demonstrating an arousal effect (Yerkes, Dodson, 1908). In stressful situations, people with high trait anxiety concentrate more on the task than people with low trait anxiety, which results in faster performance. Some studies suggested that moderate levels of anxiety could help focus attention and enhance working memory (Diamond et al., 2007; Arnsten, 2009). According to our data, even higher levels of anxiety can be beneficial for performance.

The results of this study suggest that trait anxiety may moderate the association between spatial and mathematical ability. Contrary to the generally accepted view on trait anxiety as a negative factor, we theorize that it can act as an arousal factor that actually improves performance in at least some of maths-related tasks. Altogether, our results indicate that the interplay between anxiety and mathematical cognition is complex and requires further research.

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