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SPATIAL ANXIETY AND SPATIAL PERFORMANCE IN UNIVERISTY STUDENTS IN RUSSIA AND CHINA

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Abstract

Previous studies showed inconsistent results with regards to the levels of spatial anxiety and its associations with spatial performance in males and females. In the current study, we recruited two samples from China and Russia to assess males and females on three different spatial dimensions (spatial perception, mental rotation, and spatial visualization). Eight spatial ability tests were used to measure spatial abilities the in three dimensions. The results showed that males outperformed females on all three spatial dimensions. Some differences in performance and anxiety levels were also observed across the two countries samples and are discussed in light of potential differences in selection criteria and aspects of culture. Compared to males, females had higher spatial anxiety, overall. Similar magnitudes of correlations between spatial anxiety and spatial dimesions were observed in the Russian and Chinese samples. For further analysis, the participants were divided into two groups: low spatial anxiety and high spatial anxiety according to the median of spatial anxiety for each country. Results showed significant differences between low and high spatial anxiety groups in performance on the three spatial tasks and the composite spatial ability measure. In addition, females had more anxiety on spatial perception and visualization. However, for males and females the correlations between anxiety and spatial visualization, and anxiety and spatial perception were of similar magnitudes.

Keywords: Spatial anxiety, spatial perception, mental rotation, spatial visualization, sex differences.

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1. Introduction

Spatial ability is the capacity to understand, reason and remember spatial relations among objects or space. Research has shown that spatial ability predicts mathematical achievement and career in STEM (Rohde & Thompson, 2007; Shea, Lubinski, & Benbow, 2001; Wai, Lubinski, & Benbow, 2009). Some people experience annoyance, confusion, and frustration when faced with spatial tasks - a phenomenon referred to as spatial anxiety (Lawton, 1994). A number of studies found that spatial anxiety is associated with decreased performance (longer reaction times or higher error rates) on spatial tasks (Hund & Minarik, 2006; Lawton, 1996; Schmitz, 1997). These results are consistent with the Processing Efficiency Theory (Eysenck & Calvo, 1992), according to which anxiety influences attentional capacity and the availability of short-term working memory resources. However, some studies did not find a negative association between spatial performance and spatial anxiety (Mitolo et al., 2015); or found positive associations (Mitolo et al., 2015).

Sex differences have been found in both spatial ability (see Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995 for meta-analyses) and spatial anxiety (e.g., Malanchini et al., 2017). Males on average outperform females, at least in some spatial tasks. In one study, scores for males were higher in mental rotation (d = 0.99), spatial perception (d = 0.82) and orientation strategy (d = 0.29) (Lawton, 1994). In another study of 12 year old twins, males outperformed females in rotation and visualization tasks, with 1% to 3% effect size (Tosto et al., 2014). A recent study (Toivainen, et al., in press) showed male advantage in 10 different aspects of spatial ability, with modest effect sizes (.02 to .16). Females on average showed higher spatial anxiety than males (Borella, Meneghetti, Ronconi, & De Beni, 2014; Castelli, Corazzini, & Geminiani, 2008; Malanchini et al., 2017; Malinowski, 2001; Ramirez, Gunderson, Levine, & Beilock, 2012; Schmitz, 1997). A recent study of 2928 18-21 year-old twins found higher levels of spatial anxiety in females, with sex accounting for between 1.3% and 5.5% of the variance in anxiety (Malanchini et al., 2017). Several studies found potential associations between sex differences in spatial anxiety and performance (Borella et al., 2014; Castelli et al., 2008; Malinowski, 2001). For example, Borella et al. (2014) found that males had lower spatial anxiety and better performance on spatial tasks, including mental rotation, embedded figure test and perspective tasks.

Research has also found sex differences in strategies used in spatial tasks (Lawton, 1994; Schmitz, 1997). Females who had higher spatial anxiety were likely to choose the route strategies to recall more specific features in the environment; while males were likely to choose the orientation strategy. Spatial anxiety was also shown to affect working memory capacity in females, leading to worse performance on mental rotation task. This pattern of results was not found in males (Ramirez et al., 2012). Some studies did not find significant sex differences in spatial anxiety (Hund & Minarik, 2006; Saucier et al., 2002) or spatial (navigation) ability (Hund et al., 2006).

Inconsistencies in the previous findings may be related to specificity of effects to different aspects of spatial processing. Spatial ability is composed of several factors that are differentiable from general cognitive ability (Mackintosh & Mackintosh, 2011; Wai et al., 2009). For example, Linn and Petersen (1985) defined three aspects of spatial ability: spatial perception, mental rotation and spatial visualization (see Aristova et al., 2018; Linn & Petersen, 1985). One meta-analysis found stable sex differences in mental

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rotation, small sex differences in spatial perception and no sex differences in spatial visualization (Linn & Petersen, 1985; Voyer et al., 1995).

It is possible that inconsistent findings for spatial anxiety reflect heterogeneity in spatial ability, as participants may experience anxiety only for some aspects of spatial activities/tasks, which would be masked if not specifically explored in analysis. Consistent with this, a recent study found that spatial anxiety is a multifactorial construct, including two components: navigation anxiety and rotation/visualization anxiety, which were partly separable phenotypically and aetiologically (Malanchini et al., 2017). The study also found some indication of differences in the size of sex effect for the two measures of spatial anxiety. Females had more anxiety than males towards both types of spatial activities, but effect size for rotation/visualisation was negligible (1%), with bigger effect for navigation (almost 6%).

Yet, other studies suggest more uniformity across spatial ability. For example, Toivannen et al. (in press) found sex differences across 10 aspects of spatial ability, suggesting a unified underlying ability. Moreover, recent genetically informative research also suggested a homogeneous structure of spatial ability, both phenotypically and genetically (Rimfeld et al., 2017; Shakeshaft et al., 2016).

2. Problem Statement

Previous research produced inconsistent results regarding sex differences and strengths of associations between spatial anxiety and spatial ability.

3. Research Questions

The study addressed three research questions: 1) Is spatial anxiety associated with all aspects of spatial performance?; 2) Are there sex differences in spatial anxiety and performance, as well as in the pattern of associations between spatial anxiety and performance?; 3) Do the results replicate across 2 samples of University students in China and Russia?

4. Purpose of the Study

The study aims to address the inconsistencies in the literature, examining the patterns of associations between different aspects of spatial ability and anxiety in males and females, in two diverse samples.

5. Research Methods

5.1. Participants

Participants were university students in China and Russia. In China, 211 students (91 males and 120 females) came from two universities. Their mean age was 20.2 years, ranging from 17 to 30. In Russia, 837 students (314 males and 523 females) came from four universities. Their mean age was 19.6 years, ranging from 16 to 33. All participants were right-handed, had normal or corrected-to-normal eyesight. Although all students in this study came from highly ranked universities, the two samples cannot be considered as representative. First, in both countries, different Universities operate strict selection criteria that differ across Universities and across degrees within universities. Therefore, the samples in Russia and China are not suitable for direct cross-cultural comparisons of average performance. We use the two samples to evaluate the presence of universal patterns of sex differences and associations between spatial abilities and

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anxiety. Any potential average and distribution differences will be reported here and will provide foundations for planning future cross-cultural investigations.

5.2. Measures

All students completed two computerized test batteries: Bricks (Shakeshaft et al., 2016) and King's Challenge (Rimfeld et al., 2017), that included tests of spatial ability, as well as measures of anxiety and demographic information.

5.2.1 Spatial ability

For the purposes of this study, we grouped the tests following the 3 spatial categories, suggested by Linn et al. (1985): spatial perception, mental rotation, and spatial visualization. According to this meta-analysis:

- Spatial perception tests require participants to determine spatial relationships with respect to the orientation of their own bodies, in spite of distracting information. This can be measured by 2d and 3d perception tasks.
- Mental rotation is the ability to mentally rotate a two or three dimensional figure rapidly and accurately. This can be measured by 2d and 3d rotation and 2d and 3d rotation/visualisation tasks.
- Spatial visualization is the label commonly associated with spatial ability tasks that involve complicated, multistep manipulations of spatially presented information. Complex tasks requiring visualisation, such as 2d and 3d drawing, can be used to tap into this ability.

The tasks were adapted to administration in Russia and China from the original on-line batteries (Shakeshaft et al., 2016, Rimfeld et al., 2017)

Spatial perception:

- 2D perception. The target figure represents a partially hidden 2D object. Participants need to find the same figure among a number of rotated figures (distracting information). The correct answer is the same figure in the same position (without rotation). The dark spot in the proposed figures moves (changes orientation) and hides another part of the object that was previously open.
- 3D perception. The target figure is a schematic transparent frame ("drawing") of a three-dimensional object, and the correct answer is the same object, but already "executed" in the original drawing - the 3D detail of the constructor.

Mental rotation:

- 2D rotation. This is considered the most familiar or 'natural' type of 2D rotation: the target object is rotated in the correct response but is identical in every other aspect.
- 2D rotation/visualization. The target object is partially obscured by a black dark spot. The correct response shows the same object, rotated at an angle, while the dark spot remains on the same place.
- 3D rotation. Target object remains the same in the correct response, but the 'camera' i.e., the viewpoint itself (or observer's point of view) rotates on the spot.

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- 3D rotation/visualization. The correct response is the same as target figure but rotated at the different angle in 3 dimensions.

Spatial visualization:

- 2D drawing. Participants are asked to draw the viewpoint indicated in the picture of the 3D solid as 'front' (Figure 01). The drawing that participants should produce is a 2D viewpoint of the 3D shape.

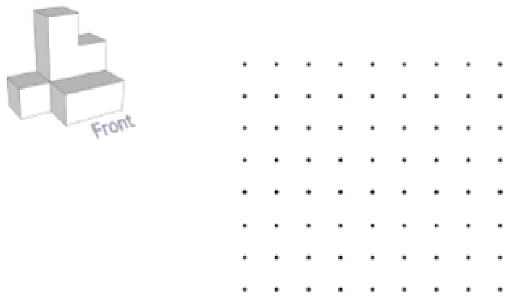

Figure 01. Sample for 2d drawing task.

- 3D drawing. Participants are presented with the coded plan (squares with numbers) and are asked to draw the 3D object corresponding to the plan (3D figure from cubes – according to the number on squares) (Figure 02).

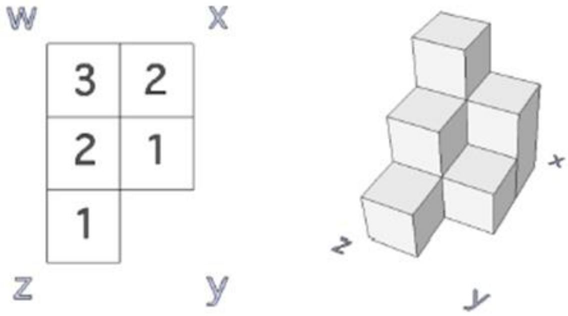

Figure 02. Sample for 3d drawing task.

5.2.2 Spatial Anxiety

The Spatial Anxiety Scale (SAS) consists of eight items containing statements about situations which can cause anxiety, such as finding the way in a new city or getting lost while going along a certain street. Participants were asked to quantify the anxiety level caused by each of the situations described on a 1–5 Likert scale (1, not at all; 5, a lot). The total score is calculated by adding together the different answers; a high score indicates that the subject has a greater spatial anxiety level. This questionnaire has two sub-scales, navigation anxiety and rotation/visualization anxiety. Both have good internal validity ($\alpha = 0.86$ for navigation anxiety; $\alpha = 0.78$ for rotation/visualization anxiety) (Malanchini et al., 2017).

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6. Findings

Firstly, we conducted MANOVA to explore sex differences for each measure in both countries. The means and standard deviations for all measures are displayed in Table 01. The universities were included as covariates. The results showed that the Chinese sample had higher spatial anxiety, compared to the Russian sample ($F(1, 1045) = 45.95$, $p < .001$). The Chinese sample outperformed the Russian sample on each spatial task. Overall in both samples males performed better in all spatial tasks, except for spatial visualization. Females had a higher spatial anxiety than males. Country and sex had an interaction effect in the spatial visualization task. Post-hoc analysis showed that in the Russian sample, males performed better than females ($F(1, 834) = 21.73$, $p < .001$), but this effect was not observed in the Chinese sample. Chinese females outperformed Russian females ($F(1, 640) = 13.47$, $p < .001$); whereas performance of males did not significantly differ for the two countries.

Table 01. Means, Standard Deviations (in brackets), and MANOVA results for each task by sex and country.

	China		**Russia**		**Country Differences**	**Sex Differences**	**Country * Sex**
	Males (N=90)	Females (N=120)	Males (N=314)	Females (N=523)	F (1, 1043)	F (1, 1043)	F (1, 1043)
Spatial Ability	54.38(9.98)	53.25(7.54)	43.23(7.58)	39.85(7.33)	242.49***	16.87***	3.20
Spatial perception	14.84(3.55)	14.17(3.28)	12.00(2.45)	11.33(2.55)	129.67***	12.26***	.01
Mental Rotation	33.48(4.38)	32.2(3.77)	24.53(4.03)	22.72(3.86)	455.07***	28.91***	.60
Spatial visualization	6.71(2.52)	6.88(2.29)	6.69(2.85)	5.8(2.59)	10.22**	3.80^{a}	6.33*
Spatial Anxiety	22.75(6.24)	26.64(5.45)	17.48(5.13)	20.47(5.79)	41.48***	64.29***	1.14

Note: Spatial ability was the composite score for three components of spatial abilities. $^{***}p < .001$; $^{**}p < .01$; $^{*}p < .05$; $^{a}p = 0.05$.

Secondly, we conducted correlational analysis. Inter-correlations among all measures by country are presented in Table 2. To assess the significance of the difference between two correlation coefficients, a series of Fisher r-to-z transformation was conducted. First, the country differences were analyzed. For the Chinese sample, the composite score of spatial ability was not significantly correlated with spatial anxiety; in the Russian sample, a weak correlation was found. However, these results did not differ significantly (Z = .79, $p = .21$). For individual dimensions of spatial ability, weak but significant correlations with spatial anxiety were observed in both samples. There were no significant differences between the correlations of spatial abilities with anxiety in the two countries' samples for the three spatial measures: Spatial perception: Z = .26, $p = .40$; Mental rotation: Z = -.66, $p = .25$; Spatial visualization: Z = -.27, $p = .39$). Table 02 also presents correlations for males and females in Russia and China separately. Overall, all correlations were

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modest. As the sample sizes in some of the groups were particularly small (e.g., 90 Chinese males), these samples were underpowered to detect weak correlations.

Table 02. Correlations between three spatial tasks and spatial anxiety by country and sex (Chinese: bottom left in black; Russian: top right in grey)

		Spatial Ability	**Spatial perception**	**Mental Rotation**	**Spatial visualization**	**Spatial Anxiety**
Total (Chinese: 211; Russian: 837)	Spatial Ability	1	0.74***	0.87***	0.81***	-0.18***
	Spatial perception	0.62***	1	0.45***	0.48***	-0.16***
	Mental Rotation	0.66***	0.35***	1	0.54***	-0.13***
	Spatial visualization	0.69***	0.36***	0.31***	1	-0.16***
	Spatial Anxiety	-0.12[a]	-0.14*	-0.18**	-0.18**	1
Males (Chinese: 90; Russian: 314)	Spatial Ability	1	0.71***	0.87***	0.81***	-0.20***
	Spatial perception	0.51***	1	0.42***	0.45***	-0.14*
	Mental Rotation	0.56***	0.39***	1	0.55***	-0.17**
	Spatial visualization	0.68***	0.25*	0.22*	1	-0.17**
	Spatial Anxiety	-0.06	-0.057	-0.28**	-0.12	1
Females (Chinese: 120; Russian: 523)	Spatial Ability	1	0.76***	0.86***	0.80***	-0.09*
	Spatial perception	0.74***	1	0.44***	0.49***	-0.13**
	Mental Rotation	0.78***	0.25**	1	0.51***	-0.03
	Spatial visualization	0.75***	0.46***	0.40***	1	-0.09*
	Spatial Anxiety	-0.07	-0.09	0.09	-0.23*	1

Note: *p < .05; **p < .01; ***p < .0001; [a]p = .09. The correlations were run on scores corrected for universities: 2 in the Chinese sample and 4 in the Russian Sample.

Because there were no significant differences between the two countries in the correlations between spatial anxiety and spatial ability, sex differences were analyzed by combining the two samples. For males, spatial anxiety was correlated with the composite score of spatial ability (r = -.16, p = .001), spatial perception (r = -.12, p = .017), mental rotation (r = -.20, p < .001) and spatial visualization (r = -.16, p = .001). For females, spatial anxiety was correlated with the composite score of spatial ability (r = -.11, p = .006), spatial perception (r = -.14, p < .001), and spatial visualization (r = -.13, p = .001), but not mental rotation (r = -.02, p = .546). The correlation coefficients between males and females did not differ significantly in the composite score of spatial ability (Z = -.83, p = .20), spatial perception (Z = -.35, p = .36) and spatial visualization (Z = -.53, p = .32). However, the difference in the correlations between spatial anxiety and mental rotation between males and females was significant (Z = -2.85, p = .002). Overall, the results suggest a very similar pattern of weak correlations between spatial anxiety and spatial ability for males and females. One exception was mental rotation ability, which was significantly correlated with spatial anxiety in males, but not females.

To further investigate the sex differences in spatial ability of individuals with high and low spatial anxiety, the participants were divided into two groups: low spatial anxiety and high spatial anxiety, according to the median of spatial anxiety for each country (25 points for the Chinese sample and 18 points

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for the Russian sample). For the Chinese sample, 115 participants (63 males) had low spatial anxiety, 96 (28 males) had high spatial anxiety. For the Russian sample, 419 participants (204 males) had low spatial anxiety, 418 (110 males) had high spatial anxiety.

MANOVA (controlling for cities/universities; Table 3) included country, gender and high/low spatial anxiety group as independent variables. The composite score of spatial ability and the three component spatial tasks were the dependent variables. Apart from the country and gender differences reported before, the results showed significant differences between low and high spatial anxiety groups in performance on the three spatial tasks and the composite spatial ability measure. The participants with low spatial anxiety performed better in all spatial tasks.

Sex by low/high anxiety status interaction was significant only on mental rotation task (Figure 03).

Table 03. The main and interaction effects of sex and spatial anxiety on spatial performance

Tasks	**Anxiety Group**	**Mean (SD)** China		**Mean (SD)** Russia		***F* (1, 1039)**						
		Gender		Gender		Country	Sex	Group	Sex* Group	Sex Country	Group Country	Sex Group Country
		Male	Female	Male	Female							
Spatial ability	Low	55.49(10.38)	54.12(6.16)	44.40(7.04)	40.27(7.39)	229.67^{***}	8.33^{**}	12.17^{**}	3.82^{a}	3.57^{b}	.14	.06
	High	51.89(8.66)	52.59(8.43)	41.05(8.08)	39.56(7.28)							
Spatial perception	Low	15.02(3.38)	14.38(2.96)	12.24(2.33)	11.53(2.52)	121.99^{***}	7.70^{**}	4.03^{*}	.49	.004	.01	.03
	High	14.43(3.94)	14.01(3.52)	11.56(2.61)	11.19(2.57)							
Mental rotation	Low	34.33(4.10)	32.38(3.51)	25.06(3.85)	22.69(3.85)	428.43^{***}	15.95^{***}	11.24^{**}	10.15^{**}	1.56	1.47	.45
	High	31.57(4.46)	32.06(3.99)	23.55(4.19)	22.74(3.88)							
Spatial visualization	Low	7.08(2.36)	7.35(2.00)	7.10(2.67)	6.06(2.65)	8.55^{**}	.52	17.08^{***}	1.72	6.68^{*}	.22	.21
	High	5.89(2.71)	6.51(2.43)	5.94(3.01)	5.63(2.54)							

Note: $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .0001$; $^{a}p = .05$; $^{b}p = .06$.

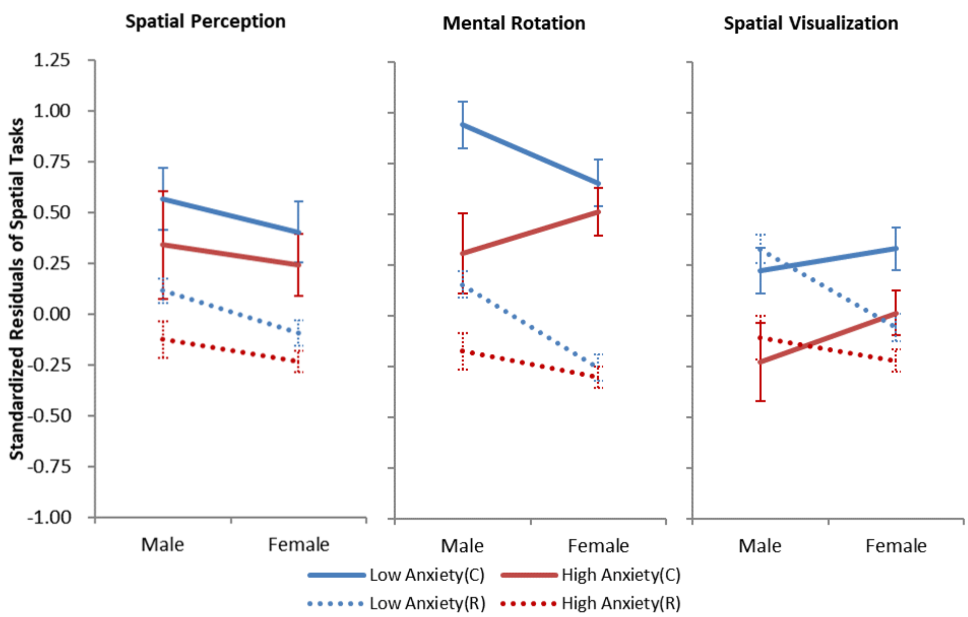

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Figure 03. The effect on sex and spatial anxiety on three spatial tasks (Left panel: spatial perception; Middle panel: mental rotation; Right panel: spatial perception). Blue lines -low spatial anxiety groups; red lines - high spatial anxiety groups. Solid lines – the Chinese sample; dotted lines - the Russian sample. Error bars indicate standard error. The scores were controlled for cities/university; C = China; R = Russia.

Post-hoc analysis showed that for the low spatial anxiety group, males performed better than females ($F(1, 531) = 23.38$, $p < .001$); for high spatial anxiety group, males and females had similar performance ($F(1, 511) = .75$, $p = .39$). Males with low spatial anxiety performed mental rotation better than males with high spatial anxiety ($F(1, 402) = 16.33$, $p < .001$). For females, no significant differences between low and high anxiety groups were found ($F(1, 640) = .89$, $p = .35$), which was in line with the correlation results. There were no significant two-way interactions between sex and country, and no significant three-way interactions between sex, low/high anxiety status and country for all the spatial tasks. These results indicate that spatial anxiety may influence mental rotation for males.

7. Conclusion

This study used three different measures of spatial ability to refine our understanding of sex differences in spatial performance and spatial anxiety. The samples in Russia and China were used to assess universal patterns of sex differences and associations between spatial anxiety and spatial abilities. The Chinese sample outperformed the Russian sample on all spatial tasks and showed higher spatial anxiety than the Russian sample. These differences in average performance may reflect some true cross-cultural differences in cognition and emotional regulation (e.g. Maercker et al. 2015). However, the differences could also be due to different entry criteria across the universities/faculties. Further cross-cultural research is needed to explore these differences. The results showed significant sex differences in all three spatial ability tasks. Males outperformed females (with the exception of mental rotation task in the Chinese sample in which males and females performed similarly). The observed male advantage in spatial ability is consistent with previous studies (Linn & Petersen, 1985; Voyer et al., 1995). Correlations between spatial anxiety and spatial tasks were modest and of similar magnitudes in the Russian and Chinese samples. Females had higher anxiety in relation to spatial tasks than males, consistent with previous studies (Borella et al., 2014; Castelli et al., 2008; Lawton, 1994; Malanchini et al., 2017; Malinowski, 2001; Ramirez et al., 2012; Schmitz, 1997). However, correlations between spatial anxiety and spatial tasks were of similar magnitudes in males and females, with the exception of mental rotation. Compared to females, males had more spatial anxiety on mental rotation task, although they performed better than females. The results also suggested differences in spatial performance between groups of students with high and low spatial anxiety. This is in line with previous results (Lawton, 1994; Malanchini et al, 2017) and supports the role of spatial anxiety individual differences and sex differences in spatial abilities. Larger samples are needed to replicate the pattern of sex differences and sex by country interactions observed in this study.

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