**Siblings’ Sex is linked to Mental Rotation Performance in Males but not Females**

**Abstract**

Research has consistently found sex differences in mental rotation. Twin research has suggested that females with male co-twins perform better than females with female co-twins on mental rotation. Because twins share both pre-natal and post-natal environments, it is not possible to test whether this advantage is due to in-uterine transmission of testosterone from males to females or due to socialisation processes. The present study explored whether the advantage of females with brothers can be observed in non-twin siblings. Participants (*N* =1,799) were assessed on mental rotation. The observed group differences were overall small: males performed significantly better than females; females with sisters performed similarly to females with brothers; importantly, males with brothers performed significantly better than both female groups. The results suggest that sex differences in mental rotation are driven by the group of males with brothers.

**Introduction**

Spatial cognitive ability refers to performance in different tasks, including visuo-spatial memory, spatial visualisation and spatial orientation (Voyer, Voyer, & Bryden, 1995). Although variation within sexes on spatial measures is larger than variation between sexes, a modest male advantage in some aspects of spatial cognition has been consistently documented (Hyde, 2005). This advantage has attracted much research interest due to its potential link with male proficiency in mathematics (Bull, Davidson, & Nordmann, 2010**;** Bull, Andrews Espy, & Wiebe, 2008) and with under-representation of women in the science, technological, engineering and mechanical (STEM) industries (Wai, Lubinski, & Benbow, 2009; Ceci, Williams, & Barnett, 2009).

Research into the origins of the gender differences in spatial cognition has explored a range of biological and environmental factors. These include organisational differences of the brain and hormonal effects, as well as socialisation, learning experiences and cultural effects (Miller & Halpern, 2014; Uttal et al., 2013; Sbarra, 2014; Reilly & Neumann, 2013; Halpern et al., 2007). The goal of research in this area is to provide a comprehensive account of the processes underlying individual differences in spatial ability and to identify efficient interventions that reduce the sex gap.

Mental rotation is one aspect of spatial ability for which sex differences have been documented (e.g. Voyer, Voyer, & Bryden, 1995). Research has shown that sex differences in mental rotation may emerge from three months of age (Moore & Johnson, 2011; Frick & Mӧhring, 2013), and that mental rotation ability improves with experience, even in infanthood (Frick & Wang, 2013).

The malleability of spatial skills is well established (see Uttal et al., 2013 for a review). Engaging in spatial activities, such as types of video games, sports and strategy games like chess has been shown to improve mental rotation performance (Spence & Feng, 2010). One study has found that ten hours of training with video games requiring spatial skill virtually eliminated sex differences in spatial attention, and significantly reduced sex differences in mental rotation ability (Feng, Spence, & Pratt, 2007). The effects of spatial training have been shown to endure for several months and may generalise across different spatial tasks (Terlecki, Newcombe & Little, 2008; Uttal et al., 2013).

Engaging in spatial activities may also produce changes in cortical thickness and activation patterns. Haier et al. (2009) found increased cortical thickness among girls who played 1.5 hours of Tetris per week over three months compared to controls. Other research has found that 18 hours of origami training over a 12 week period masculinised females’ neural activation patterns during a visuo-spatial task (Jaušovec & Jaušovec, 2012).

These findings suggest variation in spatial ability is strongly influenced by experience from an early age. The plasticity of neural substrates in response to experience also suggests that biological sex differences, such as organisational differences in the brain, may contribute to rather than determine spatial ability. Understanding the mechanisms by which males and females encounter different learning experiences is therefore an important research agenda.

Males and females do not seem to differ in the extent to which they gain from engaging in spatial activities and spatial training (Uttal et al., 2013). However, the kinds of spatial play activities thought to benefit spatial skills are both culturally male-typed and preferred by males (Voyer, Nolan & Voyer, 2000). For this reason, research has typically focused on sex differences in activity engagement, related to peer or parental socialisation of gender-typed activities (Martin et al., 2013; Wong et al., 2013) and biological precursors of activity preferences, such as prenatal testosterone exposure (Knickmeyer et al., 2005). Overall research has shown that while parental socialisation is associated with sex-typed interests, it is not strongly associated with spatial ability. Studies into prenatal testosterone exposure have shown stronger links with sex-typed interests and spatial skill in girls and boys. However, findings are inconsistent and do not account for variation within females who experience normal levels of prenatal testosterone.

Research using twin studies has recently made a contribution to describing the mechanisms underlying sex differences in mental rotation (Vuoksimaa et al., 2010; Heil et al., 2011). Two studies have shown that females with twin brothers have a replicable advantage in mental rotation performance over females with twin sisters (*d* = .30, *d* = .40; Vuoksimaa et al., 2010; Heil et al., 2011). One possibility is that females with male co-twins are exposed to higher concentrations of testosterone exposure in utero. However, specific socialisation influences of male co-twins may also contribute to this effect.

Research suggests that siblings can enrich each other’s learning environment, creating more frequent and complex opportunities for learning and scaffolding each other’s learning (Klein, Feldman, & Zarur, 2002; Azmitia & Hesser, 1993). For example, females with male siblings develop less rigid sex identities (“sex” in this context is referring to the social construct of biological sex) than females with sisters (Rust et al., 2000). As sex identity is an important predictor of sex-typed interests, females who develop more flexible sex identities may seek out more male-typed activities, affording them greater learning opportunities. Females with brothers who engage in spatial activities may also encounter these activities more; a brother could facilitate direct and vicarious spatial learning.

Increased exposure to spatial activities may not only enhance spatial skills, but also improve self-efficacy. Measures of self-efficacy, such as self-perceived ability and self-peer comparison of ability, are associated with academic ability in school (Caprara et al., 2008; Pajares & Kranzler, 1995), interest in maths (Lopez, Lent, Brown, & Gore, 1997) and career aspiration in STEM fields (Nauta, Epperson, & Kahn, 1998). Sibling sex may have an indirect effect on STEM interest and achievement via its effect on spatial ability and self-efficacy.

To address whether a socialisation, rather than hormonal, effect could account for the findings in twins, it is necessary to study non-twin siblings as hormones and socialisation in twins are confounded. One study to date has compared the effect of sibling sex on mental rotation ability in a group of twins and non-twin siblings (Heil et al., 2011). The male twin effect found by Vuoksimaa et al. (2010) was replicated only in twins, providing support for a hormonal rather than socialisation explanation. However, it is possible that this study was underpowered (*N* = 100 per group) to detect weaker effects in siblings. The effects of socialisation may be weaker between non-twin siblings as they do not develop at the same time and are more likely to experience influences of different peers. Research suggests that, although genetically non-twin siblings and non-identical (dyzogotic) twins are the same (sharing on average 50% of their variable DNA), twin siblings share on average a significantly greater proportion of their environment, relevant to cognitive development, than non-twin siblings (Koeppen-Schomerus, Spinath, & Plomin, 2003).

The present study investigates the effect of sibling sex on gender differences in mental rotation in a large sample (*N* = 1,799) of non-twin adult siblings. The study aims to examine specific socialisation practices potentially involved in the observed sex differences. We examine whether frequency of spatial play and self-efficacy vary as a function of sibling sex. As research suggests sex differences in cognitive abilities may vary across countries (Halpern et al., 2007) cultural influences on mental rotation performance will be explored through the interaction of nationality with sibling effects. The following three hypotheses will be tested:

1. Males will score more highly than females on spatial play, self-efficacy and mental rotation
2. Spatial play and self-efficacy will account for a significant proportion of variance in mental rotation
3. Females with brothers will perform better than females with sisters on the mental rotation test. This sibling effect on mental rotation performance will be moderated by the sibling effect on spatial play and self-efficacy.

**Method**

***Sample and Procedure***

University and secondary-school students were recruited via institutional email and advertisements in the United Kingdom (*N* = 570, mean age in years = 24.79, range in years = 55 years) and Russia (*N* = 1,521, mean age in years = 16.05, range in years = 57). Due to the unknown effect size and duration of any childhood sibling effects into adulthood and to create parity between this and existing study samples, a maximum age limit of 32 years was applied (boundary at upper 5th percentile; mean age in years = 16.36, range in years = 19, *N* = 1,799).

All participants completed the test online ([www.inlab.co.uk](http://www.inlab.co.uk/)), administered in English or Russian according to participant’s first language. This involved a questionnaire gathering data on siblings, spatial play tendencies in childhood and self-efficacy ratings, followed by the mental rotation test. The information sheet did not specify the study aims regarding sibling sex and cognitive performance in order to avoid demand characteristics or gender stereotype effects. The test was piloted in the United Kingdom prior to data collection (*N* =192).

***Participant-sibling sex groupings***

Previous studies have not accounted for additional siblings in the household outside of the two-person dyad, and focus on one older sibling leaving younger siblings or other older siblings close in age unaccounted for. Here participants could report up to six older and six younger siblings. Siblings absent from the participant’s childhood home environment, as well as siblings more than 7 years apart in age from the participant were excluded. This excluded siblings who were unlikely to have played a prominent role in participant’s developmental social learning.

For the main analysis, participants were grouped according to whether they had only siblings of one sex: (1) males with only female siblings (*N* = 120), (2) males with only male siblings (*N* = 151), (3) females with only female siblings (*N* = 182) and (4) females with only male siblings (*N* = 206), in order to avoid competing influences of mixed sex siblings.

Additional sibling groups were explored (Supplemental Material, Table S2). Firstly, according to whether the majority of a participant’s siblings were male or female. Secondly, according to whether participants had at least one brother in the household, in order to assess whether the presence of one brother may be sufficient to exert an effect in contrast to those reporting no brothers. Thirdly, participants with either brothers or sisters 3.5 years in age difference were grouped to assess whether a smaller age gap may be associated with stronger effects. The results from these additional analyses were very similar to those from the main analyses, and are presented in Supplemental Material.

***Engagement in spatially-oriented childhood play***

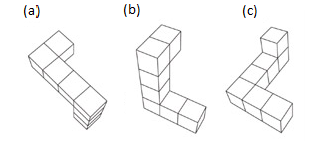
A spatial activity questionnaire was created based on a scale devised by Voyer, Nolan & Voyer (2000) and is presented in Supplemental Material (Figure S1). The original item by Voyer et al. (2000) was modified to ensure equal numbers of spatial (e.g. puzzles) to non-spatial activities (e.g. dolls), as well as a balanced mix of sporting, sedentary, male- and female-typical activities. A five-point Likert-type response scale gauged the frequency with which participants engaged in each activity, where 1 = “not often” and 5 = “very often”. An average composite “Spatial Activity” score (*Cronbach’s alpha* = .71) was calculated by summing the scores on the spatial play items and dividing them by the number of spatial play items in the questionnaire.

***Self-efficacy in spatial tasks***

Participants were also asked to rate how good they thought their spatial skills were on a five-point scale (“very poor” to “excellent”). The items included map reading, remembering object locations, or playing sports like netball or football.

***Measures of spatial ability***

The Mental Rotation Test (MRT; Vandenberg & Kuse, 1978) assesses the ability to mentally rotate an image of a geometrical target shape, and shows the most robust gender differences of any spatial cognition task favoring males (*d* = .56 - .76; Hyde, 2005). Participants must mentally rotate a three-dimensional shape in order to match it to one of two possible target shapes which are orientated differently. Rotation of target shapes ranged from 30 degrees to 345 degrees (Figure 1). The presentation of the stimuli was arranged with the original shape at the top of the screen, with the two comparison shapes presented side-by-side below. A maximum of 180 trials were presented over 3 minutes, and scores were calculated by subtracting number of incorrect trials from correct trials.



*Figure 1.**Example of mental rotation test item, adapted from Vandenberg and Kuse (1978). Target shape (a) must be matched with (b) or (c).*

***Additional cognitive measures***

Previous research into sibling sex effect has focused on mental rotation as the test that produces the most robust sex differences. We were interested in whether sibling sex effect could be observed for other abilities. As part of the same test battery, we collected data on other measures of spatial and non-verbal intelligence. Sibling effects for Ravens Progressive Matrices (Raven, 1956), the Problem Verification Test (Murphy & Mazzocco, 2008) and the Corsi Block Tapping test (Corsi, 1972) were assessed. Results for all measures were very similar, and therefore these additional measures are described and reported in Supplemental Material (S4, S5, and S6).

***Statistical analyses***

Normality and outliers were screened in males and females separately. Outliers were defined as data falling +/- 3 standard deviations from the mean, removing 38 outliers on the mental rotation test from analyses.

Means and standard deviations for mental rotation, spatial play and self-efficacy are presented for each sibling group in Table 1. Overall sex differences in mental rotation performance, spatial play and self-efficacy were assessed using ANCOVA, controlling for age and nationality. Interaction between nationality and sex on mental rotation performance was using ANCOVA controlling for age. Descriptive statistics by sex are presented in Table S1 of Supplemental Material.

Correlations *r* established the relationships between spatial play, self-efficacy and MRT performance (Table 2). The association between spatial play, self-efficacy, interaction with nationality and mental rotation was assessed using multiple regression. The results are presented in Table 3. Unstandardized regression coefficients (*B*) and standardized beta weights (*β*) with corresponding standard error (*SE*) and confidence intervals are reported.

A one-way ANCOVA assessed whether there were significant mean differences in MRT performance between sibling groups. Covariates in each ANCOVA were age and nationality. Whether spatial play or self-efficacy varied according to sibling group to affect mental rotation performance was assessed in two 2 x 4 ANCOVAs. ANCOVA analysis exploring interaction effects between nationality and sibling group on mental rotation performance was run in addition. All statistical analyses were conducted using SPSS for Windows Version 19.

**Results**

***Descriptive Statistics.***

Means and standard deviations for mental rotation performance, spatial play, and spatial self-efficacy for each sibling group are presented in Table 1.

*Table 1. Mean scores for mental rotation performance, spatial play and spatial self-efficacy across sibling groups.*

|  |  |  |  |
| --- | --- | --- | --- |
| Sibling sex group (*N*) | Mental rotation  Mean (*SD*) | Spatial play  Mean (*SD*) | Self-efficacy  Mean (*SD*) |
| Males with brothers (151) | 35.92  (9.56) | 3.00  (0.58) | 3.89  (0.98) |
| Males only sisters (120) | 35.08  (8.39) | 2.89  (0.52) | 3.72  (0.89) |
| Females only brothers  (208) | 32.29  (9.19) | 2.52  (0.44) | 3.31  (0.93) |
| Females only sisters (182) | 32.78  (10.47) | 2.51  (0.47) | 3.29  (0.98) |

***Sex differences in mental rotation, spatial play and spatial self-efficacy measures.***

ANCOVA was used to assess whether males scored more highly on mental rotation performance, spatial play and spatial self-efficacy, while controlling for age and sample nationality. In line with previous findings, males significantly outperformed females on the mental rotation test, *F* (1, 1733) = 49.73, *p* < .001, *d* = .36. Males also reported engaging in more spatial play activity than females, *F* (1, 1789) = 269.08, *p* < .001 (*d* = .85), and reported higher levels of self-efficacy in spatial tasks *F* (1, 1763) = 152.51, *p* < .001 (*d* = .62). No interaction between sex and nationality was found to affect mental rotation performance (*p* > .05).

***Do spatial play and self-efficacy predict mental rotation performance?***

Correlation and multiple regression analyses assessed the relationship between spatial play, self-efficacy and mental rotation performance. Correlations are summarised in Table 2. Positive correlations between spatial play, spatial self-efficacy and mental rotation variables indicate that greater spatial play is associated with better mental rotation performance (*r* = .13, *p* < .001). Furthermore higher spatial self-efficacy is also associated with better mental rotation performance (*r* = .11, *p* < .001). A positive association between spatial play and spatial self-efficacy was also found (*r* = .29, *p* < .001).

*Table 2. Pearson’s correlations (r) between spatial play, self-efficacy and mental rotation performance*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| N = 1,799 | | |  | |
|  | Spatial play | Self-efficacy | | Mental rotation |
| Spatial play | 1.00 |  | |  |
| Self-efficacy | .29\*\*\* | 1.00 | |  |
| Mental rotation | .13\*\*\* | .11\*\*\* | | 1.00 |

*\*\*\*p < .001, \*\* p < .01, \* p < .05,*

A multiple regression analysis assessed whether spatial play and spatial self-efficacy measures were significant predictors of mental rotation ability, and whether they interacted with nationality. The measures were significant but very weak predictors explaining only 2% of the variance in mental rotation (*R²* = .02, *F* (6, 1706) = 6.70, *p* < .001). Spatial play was the strongest predictor of mental rotation performance, with greater amounts of spatial play significantly predicting better mental rotation performance (*B* = 1.70 (*SE* = .50), *t* (1706) = 3.42, *p* < .001). Higher ratings of self-efficacy also predicted better mental rotation performance (*B* = .86 (*SE* = .30), *t* (1706) = 2.90, *p* = .003). No interaction between spatial play or self-efficacy with nationality was associated with change in mental rotation performance (*p* > .05).

*Table 3. Multiple regression with mental rotation performance as criterion.*

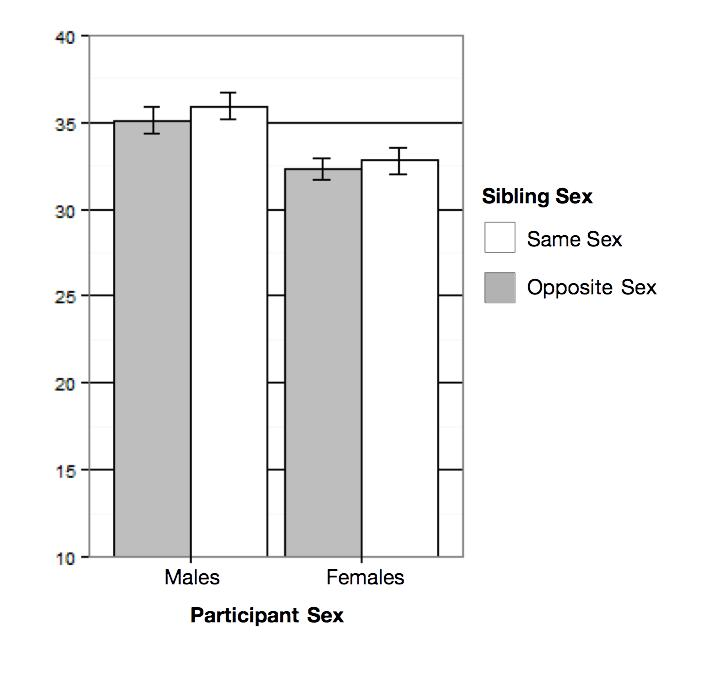
|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Dependent variable: mental rotation performance** | | | | | | | |
| **Independent variable** | | *B* | *β* | *SE* | *t* | 97.5% CI for *β* lower bound | 97.5% CI for *β* upper bound | *p*-value |
| Age | | 0.21 | 0.05 | 0.12 | 1.63 | -0.04 | 0.43 | 0.10 |
| Nationality | | -1.39 | -0.01 | 3.35 | -0.42 | -7.96 | 5.18 | 0.68 |
| Spatial play | | 1.69 | 0.10 | 0.50 | 3.42 | 0.72 | 2.67 | <0.001 |
| Self-efficacy | | 0.86 | 0.08 | 0.30 | 2.90 | 0.28 | 1.44 | 0.003 |
| Spatial play x Nationality | | 0.68 | 0.02 | 1.26 | 0.54 | -1.79 | 3.18 | 0.59 |
| Self-efficacy x Nationality | | -0.13 | -0.01 | 0.59 | -0.23 | -1.31 | 1.03 | 0.82 |

*Note: Age and nationality (UK vs. Russia) were included in the model as control variables.*

***Do females with brothers perform better on the mental rotation test than females with sisters?***

Mean scores on the mental rotation test were compared between sibling groups using one-way ANCOVA, controlling for effects of covariates age and nationality. A significant main effect of sibling sex was found, *F* (3, 636) = 5.59, *p* < .001. Mean differences between sibling groups are illustrated in Figure 2. Post-hoc comparisons were made using bonferroni-corrected pairwise t tests, revealing no difference in mental rotation performance between females with brothers (*M* = 32.29, *SD* = 9.19) and females with sisters (*M* = 32.78, *SD* = 10.47); and no difference between males with brothers (*M* = 35.92, *SD* = 9.56) and males with sisters (*M* = 35.04, *SD* = 8.39). However males with brothers performed significantly better than both groups of females, whereas males with sisters did not differ from either female group. Separate analysis of interaction effects between sibling group and nationality was non-significant (*p* > .05).

The same model using sibling groups of only 3.5 year age gap returned no significant difference in mental rotation performance between females with brothers (*M* = 31.8, *SD* = 9.35) and females with sisters (*M* = 31.86, *SD* = 9.69). The results of this analysis are presented in Table S3 as supplementary information.



*Figure 2. Mental rotation performance as a function of participant sex (males vs. females) and sibling sex (same sex vs. opposite sex). Error bars indicate standard errors.*

*Table 4. Differences in mental rotation performance between sibling sex groups*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | 95% Confidence interval | |
| (I)  Sibling sex group | (J)  Sibling sex group | Mean difference  (I - J) | *SE* | Cohen’s *d* | Lower bound | Upper bound |
| Male OS | Male SS | -0.90 | 1.19 | -.11 | -3.95 | 2.15 |
| Female OS | Male SS | -3.78\*\* | 1.06 | -.41 | 1.04 | 6.51 |
| Female SS | Male SS | -3.22\* | 1.07 | -.31 | -5.89 | -0.46 |
| Female OS | Male OS | -2.88 | 1.11 | -.31 | 0.01 | 5.75 |
| Female SS | Male OS | -2.33 | 1.13 | -.24 | -5.23 | 0.58 |
| Female SS | Female OS | 0.56 | 0.98 | .05 | -1.97 | 3.08 |

*\*\* p < .01, \* p < .05*

***Effect of sibling sex, spatial play and spatial self-efficacy on mental rotation performance***

Two 2 x 4 ANCOVAs (high/ low spatial play or self-efficacy x sibling sex) assessed whether the differences in mental rotation performance between sibling groups were related to differences in spatial play or self-efficacy. There was no interaction effect between sibling group and spatial play on mental rotation performance, *F* (3, 630) = 1.91, *p* = .13. Similarly no interaction effect was found between spatial self-efficacy and sibling group on mental rotation performance, *F* (3, 631) = .44, *p* = .25.

**Discussion**

The main aim of this study was to explore whether having a sibling of a particular sex has an effect on an individual’s mental rotation performance. A replicable advantage in mental rotation performance among females who have brothers has been demonstrated in twins (Vuoksimaa et al. 2010; Heil et al, 2011). However, as twins share both prenatal and postnatal environments, these studies were unable to establish the mechanism underlying this effect. To test whether the effect stems from prenatal hormone transmission or post-natal interaction between siblings, we collected data on the number, age and gender of non-twin siblings in a large sample of adults. Data was also collected on participant’s tendencies toward spatially-oriented play during childhood, their self-efficacy around spatial tasks, and performance on a mental rotation test.

Hypothesis (i) was supported; in line with previous findings, males engaged in more spatial play, reported higher spatial self-efficacy in their spatial skills and performed better on the mental rotation test. The magnitude of the effect of sex on mental rotation ability (*d* = .36) is consistent with previously reported meta-analysed effects (Voyer et al., 1995; *d* = .37). These findings suggest that sex differences in mental rotation are modest but robust. Furthermore, the study indicated a strong (*d* = .85) sex difference in spatial play, with males engaging significantly more in spatial play than females. While some research suggests that sex differences in cognition are disappearing as a result of increasing equality between the sexes (Lippa et al., 2010), this finding suggests that mental rotation ability and spatially-relevant interests continue to be dimorphic to some extent.

Hypothesis (ii) was also supported, with spatial play and self-efficacy being significant predictors of mental rotation performance. In light of evidence suggesting sex differences in cognitive abilities change across cultures (Halpern et al., 2007) it is interesting to note that nationality did not interact with spatial play or self-efficacy. This speaks to the theory that spatially-oriented play preferences in children may be biologically determined. Indeed, spatial play and self-efficacy were highly correlated and it is possible that self-efficacy is a product of learning experiences driven by biological predisposition.

Extending this point, hypothesis (iii) proposed that females with brothers would perform better than females with sisters on the mental rotation test, and that this would be related to differences in spatial play and self-efficacy. Contrary to previous findings in twins, females with brothers did not outperform females with sisters on the mental rotation test. Further analyses (presented in Supplemental Material) showed no effect in females of having more than one brother or having more brothers than sisters. These results are in line with the only other study to date which attempted to replicate the twin effect among non-twin siblings (Heil et al., 2011).

The absence of the sibling effect in non-twins may indicate that the observed effect in twins is a result of prenatal hormonal transmission. Alternatively, the result may indicate that social learning processes in twins differ from those in non-twin siblings; twins may interact more or with higher intensity due to their age and phenotypic similarity. This study extended analyses to look at siblings 3.5 years apart in age for comparison with the 7 year age gap criterion used in main analyses. There was no change to the absence of sibling effect in females with brothers as opposed to sisters in this group despite being closer in age. However, group sample sizes were small and it is possible that the analysis was underpowered to detect any subtle effects. Further research assessing age gap effects with a larger sample is warranted.

Regarding the social influence of siblings on extent of spatial play or self-efficacy, no interaction was found between sibling group and covariates on mental rotation performance. It appears that spatial play and self-efficacy are important contributors to mental rotation performance, but they may not be influenced by social interaction with siblings.

Interestingly, a sibling sex effect on mental rotation performance was observed for males with brothers. Whilst males with sisters performed similarly to both female groups, males with brothers performed significantly better in comparison to both female groups. This finding suggests that the robust sex differences in mental rotation are stronger for the group of males with brothers, and contrasts with the findings of the previous study (Vuoksimaa et al., 2010), in which males with brothers and males with sisters performed similarly.

Despite efforts to maximise power through on-line data collection and the use of the mental rotation test that shows robust sex differences, the opportunity sampling used in this study led to unequal and possibly insufficiently sized sibling sex groups.

Longitudinal research is needed to explore whether the presence and magnitude of the sibling sex effect differs across development. Although this study provided indirect support for the hormonal account of the sibling effect observed in twins, it would be premature to rule out the contribution of socialisation. Further research should explore the role of different types of socialisation between siblings in spatial ability development, factoring in the size of age gap between participant and sibling. Ultimately, this research may lead to better understanding of the causes of the persistent sex imbalance in STEM fields, and contribute to strategies that counter this through enhancing spatial ability.

ACKNOWLEDGEMENTS: The authors gratefully acknowledge the support from the

Government of the Russian Federation (grant 11.G34.31.0043)

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