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Siblings' sex is linked to mental rotation performance in males but not females☆

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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 ($N = 1799$) 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.

1. 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, Andrews Espy, & Wiebe, 2008; Bull, Davidson, & Nordmann, 2010) and with under-representation of women in the science, technological, engineering and mechanical (STEM) industries (Ceci, Williams, & Barnett, 2009; Wai, Lubinski, & Benbow, 2008).

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; Halpern et al., 2007; Reilly & Neumann, 2013; Sbarra, 2014; Uttal et al., 2013). 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 et al., 1995). Research has shown that sex differences in mental rotation may emerge from three months of age (Frick & Möhring, 2013; Moore & Johnson, 2011), 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; Robert & Héroux, 2004). 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, Karama, Leyba, and Jung (2009) found increased cortical thickness among girls who played 1.5 h of Tetris per week over three months compared to controls. Other research has found that 18 h of origami training over a 12 week

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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., 2014; 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 (Heil, Kavšek, Rolke, Beste, & Jansen, 2011; Vuoksimaa et al., 2010). Two studies have shown that females with twin brothers have a replicable advantage in mental rotation performance over females with twin sisters ($d = .30$, $d = .40$; Heil et al., 2011; Vuoksimaa et al., 2010). 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 (Azmitia & Hesser, 1993; Klein, Feldman, & Zarur, 2002). 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 (dizygotic) 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 ($N = 1799$) 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 country with sibling effects. The following three hypotheses will be tested:

i. Males will score more highly than females on spatial play, self-efficacy and mental rotation.
ii. Spatial play and self-efficacy will account for a significant proportion of variance in mental rotation.
iii. 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.

2. Method

2.1. 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 ($N = 1521$, 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), 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 ($N = 192$).

2.2. 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