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Sex differences in non-verbal and verbal abilities in childhood and adolescence

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ABSTRACT

Twin research has shown that females with male co-twins perform better than females with female co-twins on mental rotation. This beneficial effect of having a male sibling on spatial ability could be due to in-uterine transmission of testosterone from males to females (the Twin Testosterone Transfer hypothesis, TTT). The present study explored sex differences and the TTT in non-verbal and verbal abilities in a large sample of twins assessed longitudinally at 2, 3, 4, 7, 9, 10, 12, 14 and 16 years of age. Females scored significantly higher than males on both verbal and non-verbal abilities at ages 2, 3 and 4. Males scored significantly higher than females on verbal ability at ages 10 and 12. The effect sizes of all differences were very small. No sex differences in non-verbal or verbal abilities were found at 7, 9, 14 and 16 years of age. No support for the TTT was found at any age. The findings indicate that the twin testosterone transfer effect occurs only for specific cognitive abilities, such as mental rotation.

1. Introduction

Research findings have traditionally indicated that sex differences favoring males appear in non-verbal abilities (e.g. Voyer, Voyer, & Bryden, 1995), while sex differences favoring females appear in verbal abilities (Hyde & Linn, 1988). However, the distinction is more nuanced, which is reflected in the more recent literature on sex differences. For example, within verbal abilities males often do better on verbal analogies (Colom, Contreras, Arend, Leal, & Santacreu, 2004), whereas females outperform males on natural language competencies, reading and writing (Geary, 2010; Stoet & Geary, 2013). Non-verbal abilities refer to 'the skill in representing, transforming, generating, and recalling symbolic, non-linguistic information' (Linn & Petersen, 1985). Verbal abilities refer to measures of language usage, such as grammar, spelling, reading, writing, verbal analogies, vocabulary and oral comprehension (Halpern, 2000). In this paper, we adopt these definitions for verbal and non-verbal skills for convenience.

Although research suggests that sexual differentiation in certain cognitive abilities exists, sex differences in general cognitive ability are overall small, if not negligible (Aluja-Fabregat, Colom, Abad, & Juan-Espinosa, 2000; Colom & Garcia-Lopez, 2002; Colom, Juan-Espinosa, Abad, & Garcia, 2000). Cognitive sex differences also change over time (Miller & Halpern, 2014). Environmental changes, such as changes in education policies, are likely to have cohort-specific effects (Miller & Halpern, 2014). There is currently mixed evidence on sex differences in verbal and non-verbal abilities. Some studies have shown small to moderate sex differences in non-verbal and verbal ability in childhood and adolescence (e.g. Feldman et al., 2000; Galsworthy, Dionne, Dale, & Plomin, 2000; Goldbeck, Daseking, Hellwig-Brida, Waldmann, & Petermann, 2010; Jensen & Reynolds, 1983; Lynn & Irwing, 2004; Pezzuti & Orsini, 2016). For example, males outperformed females in vocabulary tasks in German and Italian samples of children and adolescents ($d = 0.25$, Goldbeck et al., 2010; $d = 0.10$, Pezzuti & Orsini, 2016). Another study, based on a large sample of pupils aged 11–12 years in the UK, showed that females performed better than males in both verbal ($d = 0.15$) and non-verbal ($d = 0.03$) reasoning (Strand, Deary, & Smith, 2006).

A meta-analysis of studies on sex differences in the Raven's Progressive Matrices showed no significant differences between ages 6 and 14 years; however, males outperformed females at 15 years onwards (Lynn & Irwing, 2004). Additionally, a meta-analysis of studies on sex differences in the Colored Progressive Matrices reported that males outperformed females ($d = 0.21$) in a sample of children age 5 to 11 years (Lynn & Irwing, 2004). Another, more recent, study reported

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that males had significantly higher scores in a written mathematics test than females ($d = 0.15$), whereas females performed better in the written Danish ($d = 0.49$) and oral English tests ($d = 0.20$; Ahrenfeldt, Petersen, Johnson, & Christensen, 2015).

A recent meta-analysis of the National Assessment of Educational Progress assessments in the USA reported that males outperformed females in mathematics ($d = 0.10$) and science achievement ($d = 0.13$) in the period of 1990–2011 (Reilly, Neumann, & Andrews, 2015). Furthermore, large sex differences (close to one standard deviation), favoring males, have been consistently documented in some aspects of spatial cognition, such as mental rotation (Hyde, 2005; 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; Quinn & Liben, 2013). This male advantage has attracted much research interest due to its potential link with male proficiency in mathematics (Bull, Davidson, & Nordmann, 2010; Bull, Espy, & Wiebe, 2008) and with under-representation of women in the science, technological, engineering and mathematical (STEM) industries (Ceci, Williams, & Barnett, 2009; Wai, Lubinski, & Benbow, 2009). However, several studies did not report significant sex differences in many verbal or non-verbal ability tasks across development (e.g. Goldbeck et al., 2010; Pezzuti & Orsini, 2016).

Research into the biological factors that may contribute to sex differences in cognition suggests that sex hormones, such as testosterone, can influence cognitive development (Kung, Constantinescu, Browne, Noorderhaven, & Hines, 2016). For example, a recent study reported that testosterone, measured in saliva samples collected at 1–3 months of age, negatively predicted parent-reported expressive vocabulary size at 18–30 months of age in boys and in girls (Kung et al., 2016). The study further showed that postnatal testosterone contributed to sexual differentiation by mediating the effect of sex on expressive vocabulary (Kung et al., 2016). Extraneous administration of testosterone was found to have temporary positive effects on cognition: exogenous administration of testosterone improved spatial ability and verbal memory in older men (Cherrier et al., 2001); as well as spatial ability in female to male transsexuals (Slabbekoorn, van Goozen, Megens, Gooren, & Cohen-Kettenis, 1999). However, a study has shown that naturally occurring fluctuations in testosterone levels could not explain differences in performance on spatial ability tasks, within or between sexes, in a sample of young adults (Puts et al., 2010).

Prenatal exposure to testosterone is argued to have more permanent, organizational effects on brain development in comparison to the effects of postnatal exposure to testosterone (Brizendine, 2007). Research on clinical populations reported higher performance on mental rotation tasks in women with congenital adrenal hyperplasia (CAH)—who are exposed to high levels of prenatal androgens in utero—in comparison to healthy women (Berenbaum, Bryk, & Beltz, 2012). Furthermore, a meta-analysis of studies on the association between CAH and spatial ability found that females with CAH perform better on spatial tasks in comparison to controls (Puts, McDaniel, Jordan, & Breedlove, 2008). Conversely, another study has shown that higher levels of prenatal testosterone in amniotic fluid were negatively correlated with vocabulary size at ages 12 and 24 months (Lutchmaya, Baron-Cohen, & Raggatt, 2001). It is likely that prenatal testosterone exposure affects the development of natural language competencies (e.g., mean length utterance and other measures in which girls often show a modest advantage over boys) rather than other verbal abilities (e.g. vocabulary or grammar - measured in this study). However, it is also possible that prenatal testosterone may affect the brain in a way that subsequent learning is affected, therefore extending its influence to different measures of verbal ability. Other studies have also reported that prenatal testosterone levels are associated with later behavior, physiology and cognition (Berenbaum & Beltz, 2011; Cohen-Bendahan, van de Beek, & Berenbaum, 2005; Hines, 2010).

According to an evolutionary account, prenatal hormonal environment is one biological mechanism influencing sex differences in certain cognitive abilities based on sexual selection (Geary, 2010). For example, the better developed basic language competencies in females, beneficial for intra-sex competition, could be partly explained by prenatal hormonal effects (Geary, 2010). Similarly, prenatal testosterone could explain to some extent males' better performance in certain spatial abilities, specifically in 3D mental rotation. It is argued that the elaboration of some neurocognitive systems, that have evolved for navigating and tracking movement in the 3-dimensional universe, is more beneficial for males than for females (Geary, 1995). Based on the evolutionary processes, the influence of prenatally transferred testosterone may be presented only for those higher order abilities that are dependent on more basic, prenatally organized abilities. The influence could be seen, for example, if mathematical tasks require more basic visuo-spatial processing ability, or if language processing tasks involve phonetic decoding (Geary, 2014).

Research using twin samples has made a contribution towards understanding the potential effect of prenatal testosterone exposure to sex differences in cognition (Tapp, Maybery, & Whitehouse, 2011). Specifically, two studies have shown that females with twin brothers have an advantage in mental rotation performance over females with twin sisters ($d = 0.40$, Heil, Kavšek, Rolke, Beste, & Jansen, 2011; $d = 0.30$, Vuoksimaa et al., 2010). One explanation for this phenomenon is that females with male co-twins are exposed to higher concentrations of testosterone in utero. Alternatively, the advantage may stem from socialization with a male co-twin that may include activities important for spatial development. One recent study did not support the socialization explanation, but instead provided indirect evidence for the TTT. The study used a sample of non-twin siblings and reported that females with brothers did not outperform females with sisters on the mental rotation test (Frenken et al., 2016). However, a recent twin study did not find evidence for the TTT (Ahrenfeldt et al., 2015). The study found small sex differences in mathematics, English and Danish ($d = 0.15$–0.49) in an adolescent sample, but the sex differences were not explained by sex of the co-twin.

To summarize, to date research is inconsistent regarding the role of testosterone transmission in the observed sex differences in cognitive abilities. It is possible that the effects are only present for some abilities and/or at certain time in development. Alternatively, the effects could be very small and therefore require large samples to be detected. The present study uses a large longitudinal twin sample to estimate sex differences in non-verbal and verbal abilities over time, using a variety of measures. The study also investigates the influence of prenatal testosterone on these differences by comparing females with male co-twins to females with female co-twins. Evidence for the TTT hypothesis indicates that the effect may be particularly prominent in visuo-spatial abilities (Tapp et al., 2011). Two previous studies using adult samples have demonstrated that women with twin brothers outperform women with twin sisters in a non-verbal task of mental rotation. It can therefore be expected that evidence for TTT can be found in non-verbal abilities. Previous research with singletons found a negative correlation between prenatal testosterone levels and expressive vocabulary in the early childhood (Kung et al., 2016). We therefore expect that females with male twin brothers will perform worse on verbal ability tasks than females with female twin sisters.

The study addresses three main research questions:

(i) Are there sex differences in non-verbal and verbal abilities at 2, 3, 4, 7, 9, 10, 12, 14 and 16 years of age?
(ii) Do females with male co-twins outperform females with female co-twins on non-verbal abilities at 2, 3, 4, 7, 9, 10, 12, 14 or 16 years of age?
(iii) Do females with male co-twins perform worse than females with female co-twins on verbal abilities at 2, 3, 4, 7, 9, 10, 12, 14 or 16 years of age?