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Academic performance of opposite-sex and same-sex twins in adolescence: A Danish national cohort study

Linda Ahrenfeldt [a,*], Inge Petersen [a], Wendy Johnson [b], Kaare Christensen [a,c]

[a] The Danish Twin Registry, Epidemiology, Biostatistics and Biodemography, The University of Southern Denmark, 5000 Odense, Denmark
[b] Department of Psychology, The University of Edinburgh, Edinburgh, Scotland, UK
[c] Department of Clinical Biochemistry and Pharmacology and Department of Clinical Genetics, Odense University Hospital, 5000 Odense, Denmark

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ABSTRACT

Testosterone is an important hormone in the sexual differentiation of the brain, contributing to differences in cognitive abilities between males and females. For instance, studies in clinical populations such as females with congenital adrenal hyperplasia (CAH) who are exposed to high levels of androgens *in utero* support arguments for prenatal testosterone effects on characteristics such as visuospatial cognition and behaviour. The comparison of opposite-sex (OS) and same-sex (SS) twin pairs can be used to help establish the role of prenatal testosterone. However, although some twin studies confirm a masculinizing effect of a male co-twin regarding for instance perception and cognition it remains unclear whether intra-uterine hormone transfer exists in humans. Our aim was to test the potential influences of testosterone on academic performance in OS twins. We compared ninth-grade test scores and teacher ratings of OS ($n = 1812$) and SS ($n = 4054$) twins as well as of twins and singletons ($n = 13{,}900$) in mathematics, physics/chemistry, Danish, and English. We found that males had significantly higher test scores in mathematics than females (.06–.15 SD), whereas females performed better in Danish (.33–.49 SD), English (.20 SD), and neatness (.45–.64 SD). However, we did not find that OS females performed better in mathematics than SS and singleton females, nor did they perform worse either in Danish or English. Scores for OS and SS males were similar in all topics. In conclusion, this study did not provide evidence for a masculinization of female twins with male co-twins with regard to academic performance in adolescence.

Introduction

In human foetuses, large sex differences in testosterone levels exist from early in gestation, and this hormone difference exerts permanent effects on brain development and behaviour (Hines, 2010). The literature regarding sex differences in cognitive abilities is reasonably consistent. Differences in quantitative abilities have received most attention because of the large sex differences in choice of professional careers in natural science and mathematics favouring males (Halpern et al., 2007). Males tend to outperform females on most measures of visuospatial abilities (though distributions overlap considerably, as is the case for all sex differences in cognitive abilities), which may contribute to the sex differences in test scores in mathematics and natural science (Halpern et al., 2007). However, the magnitude of this sex difference appears to increase with age (Bharadwaj et al., 2012; Hyde, 2005). It seems that the male advantage tends to emerge as the mathematical concepts being taught require more reasoning, more spatial abilities, and more complex problem-solving (Haworth et al., 2010; Hyde et al., 1990), though recent changes in the patterns suggest that cultural expectations also play a role (Lindberg et al., 2010). Conversely, sex-differences favouring females in verbal abilities such as reading, writing, and language usage are well documented in the literature (Halpern et al., 2007; Hedges and Nowell, 1995), and the superiority of females in verbal abilities continues into adulthood (Strand et al., 2006). While school achievement measures are not direct measures of abilities, they are generally strongly correlated with them (Bartels et al., 2002; Naglieri and Bornstein, 2003).

Human studies of prenatal hormone effects were initially motivated by experimental studies in animals. The study by Phoenix et al. (Phoenix et al., 1959) was the first to show that prenatal exposure to steroid testosterone could alter brain structure and function and result in behavioural differences (Phoenix, 2009). The study found that female guinea pigs that were exposed to testosterone prenatally showed masculinized behaviour in adulthood. Since then, several studies of non-human mammals have demonstrated effects of testosterone on neurobehavioural sexual differentiation (Constantinescu and Hines, 2012). Evidence that testosterone also influences human neurobehavioural development is to a great extent derived from studies of individuals who develop in atypical hormone environments (Constantinescu and Hines, 2012),

* Corresponding author.
E-mail addresses: lahrenfeldt@health.sdu.dk (L. Ahrenfeldt), ipetersen@health.sdu.dk (I. Petersen), wendy.johnson@ed.ac.uk (W. Johnson), kchristensen@health.sdu.dk (K. Christensen).

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and the best-studied clinical condition is congenital adrenal hyperplasia (CAH) (Cohen-Bendahan et al., 2005). Females with CAH, who produce high levels of adrenal androgens from early in gestation due to an autosomal recessive disorder, show increased male-typical behaviour and decreased female-typical behaviour despite postnatal hormone treatment (Hines, 2011). The most consistent findings have emerged from studies of childhood play. These studies found that females with CAH show increased male-typical and decreased female-typical toy, activity and playmate preferences (Cohen-Bendahan et al., 2005; Hines, 2011). Additionally, androgens also appear to affect cognition in females with CAH. A meta-analysis of nine samples (Puts et al., 2008) found that CAH females show higher spatial performance than do control females.

OS twins have been suggested to provide another opportunity to test the effects of prenatal testosterone exposure (Miller, 1994; Resnick et al., 1993), and higher testosterone in OS females is inferred on the basis of animal studies in e.g. rats and mice which have demonstrated that exposure to sex hormones is influenced by the intrauterine foetal position (Ryan and Vandenbergh, 2002). Male foetuses have greater concentrations of testosterone than females, and females produce higher amounts of estradiol than males (vom Saal, 1989), but any foetus (male or female) located between two male foetuses has a higher concentration of testosterone than a female foetus located between two female foetuses (Ryan and Vandenbergh, 2002; vom Saal, 1989). This phenomenon results in females appearing masculinized in several anatomical, physiological and behavioural traits such as aggressive behaviour and reproductive organs (Ryan and Vandenbergh, 2002). Likewise, female foetuses that develop between other female foetuses show more feminized traits as adults, for example earlier vaginal opening (Ryan and Vandenbergh, 2002). Thus, intrauterine position and the possibility of steroid transfer of especially testosterone from one foetus to another during foetal life have effects in animals (Ryan and Vandenbergh, 2002; vom Saal, 1989).

The twin testosterone transfer (TTT) hypothesis reflects the possibility that human sex hormones is transferred between twins, most likely by diffusing across foetal membranes (Even and vom Saal, 1992). However, there is no direct evidence that females with a male co-twin have been exposed to sex-atypical hormone levels, and the literature on masculinization in OS female twins is inconsistent (Tapp et al., 2011). Some twin studies confirm the masculinizing effect of a male co-twin on females, for instance regarding physiological traits such as tooth size (Dempsey et al., 1999; Ribeiro et al., 2013), otoacoustic emissions (sounds produced by the inner ear) (McFadden, 1993), second-to-fourth-finger-length ratio (van Anders et al., 2006), maternal fitness (Lummaa et al., 2007), and leukocytes telomere length (Benetos et al., 2014), but other large studies have reported negative findings (Gaist et al., 2000; Medland et al., 2008a; Medland et al., 2008b). Moreover, several studies have failed to find behavioural differences between OS and SS females including toy preferences (Henderson and Berenbaum, 1997; Rodgers et al., 1998), eating disorders (Baker et al., 2009; Raevuori et al., 2008), social behaviour and friendship in preschool children (Laffey-Ardley and Thorpe, 2006), and autistic symptomatology (Ho et al., 2005). However, two studies have found greater sensation-seeking, including experience-seeking, in OS females compared with SS females (Resnick et al., 1993; Slutske et al., 2011). These latter findings suggest effects of hormone exposures on later behavioural development, although psychosocial explanations cannot be excluded (Resnick et al., 1993).

More evidence exists for the effect of being an OS twin on cognitive and perceptual abilities than for other sex-typed characteristics (Tapp et al., 2011). In agreement with earlier CAH studies (Berenbaum et al., 2012; Puts et al., 2008), recent co-twin studies (Heil et al., 2011; Tapp et al., 2011; Vuoksimaa et al., 2010) provide evidence for effects of prenatal testosterone on cognitive abilities. According to two twin studies that included 200 and 471 study participants, respectively (Heil et al., 2011; Vuoksimaa et al., 2010), OS females were found to have higher mental rotation (MRT) ability (the ability to imagine objects from a perspective other than the one depicted) than SS and singleton females. One of the studies (Heil et al., 2011) also demonstrated that OS females have higher mental rotation performance than non-twin females raised with a slightly elder brother (born within 18 months) which helps exclude possible socialisation effects of growing up with a twin brother.

Most studies that have investigated co-twin effects in males, have failed to identify differences between OS and SS male twins in the direction predicted by the TTT hypothesis (Cohen-Bendahan et al., 2005; Tapp et al., 2011). However, animal studies (Ryan and Vandenbergh, 2002; vom Saal, 1989) and limited evidence from human studies suggest that excess testosterone in males might further masculinize traits such as disordered eating (Culbert et al., 2008) and brain volume (Peper et al., 2009). Moreover, one study (Ho et al., 2005) reported that sub-threshold autistic symptomatology rated by parents was higher in SS than in OS male twins aged 7 to 15, which may support the TTT hypothesis.

Outcome used in the present study is ninth grade test scores and teacher assessment of academic performance (outcomes which are of great importance for both the twins and their parents). Academic achievement is different from abilities and potentially more likely to be influenced by environmental/social factors (Bacete and Remirez, 2001). However, a high correlation (.70 to .74 in average) between standardised achievement tests and IQ had been shown (Naglieri and Bornstein, 2003), and the correlation between IQ and national achievement tests, such as the test used here, have similar correlations among 12-year-old school children (Bartels et al., 2002). Studies comparing the academic performance of OS and SS twins are scarce. Only one recent study of 13,368 twins and 837,752 singletons born during 1973–1981 in Sweden has investigated differences between OS and SS twins in grade point average (Hjern et al., 2012). The study found that SS twins of both sexes had slightly higher average scores in ninth grade than OS twins, and that they more often than OS twins had attained a university degree by the age of 27–35. However, the differences in grade point average were very small and non-significant, and the authors did not include topic specific analyses and did not discuss possible reasons for their results.

The overall aim of this study was to test the potential influences of testosterone on academic performance in OS twins. The reason for studying OS vs SS twins was to test behavioural effects of prenatal hormone, and therefore the effects of co-twin sex should be tested on measures that show sex differences such as academic performance in adolescence. Additionally, the evidence on spatial abilities in females with CAH supports arguments for prenatal testosterone effects on mathematical abilities (Halpern et al., 2007). This study relies on a large sample size with the existence of control variables such as parental education. Furthermore academic performance was analysed as topics, resulting in more detailed investigation of possible sex differences and whether these differences are transmitted to differences of OS and SS twins. Our primary objective was to compare academic performance in mathematics, physics/chemistry, Danish and English for female and male members of OS and SS twin pairs to test for an interaction between sex and OS/SS status. Secondly, we examined whether the OS/SS twin groups differed in performance from the general population. This was achieved by comparing the OS twins and the SS twins born in Denmark during 1986–1990 for each sex, with a 5% random sample of singletons born in Denmark during the same period and surviving until January 1, 2003.

Material and methods

Material

We included information from four registers: the Danish Demographic Database, including information on parental identities, deaths, migrations, and adoptions (Petersen, 2000); the Integrated Database for Labour Market Research containing information on the highest