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Prenatal Exposure to Androgens and Gender Socialisation Effects on Children's Academic Interests

Laia Sánchez Guerrero · Pia S. Schober · Birgit Derntl

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Abstract Previous studies have documented gender differences in fields of study as well as interest in school subjects. Boys are on average more interested in mathematics, and girls show greater interest in languages. The extent to which these disparities are the result of biological or environment influences is still an open debate. On the one hand, brain organisation theory suggests that physiological and behavioural differences may be linked to prenatal hormone levels. On the other hand, sociological and psychological perspectives highlight the importance of gen-

Online Appendix: <https://kzfss.uni-koeln.de/sites/kzfss/pdf/Sanchez-Guerrero-et-al.pdf>

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der socialisation. This paper combines biological, psychological, and sociological perspectives to examine the emergence of gendered academic interests in children.

The study draws on data from 9-year-old children from the Avon Longitudinal Study of Parents and Children (ALSPAC). Our results suggest that for both boys and girls, medium to high compared with low prenatal exposure to circulating maternal testosterone might increase children's interests in mathematics relative to English, although results vary depending on how prenatal testosterone exposure is measured. As the distributions of prenatal androgen exposure and the relationships with maths versus English interests are very similar for boys and girls, prenatal androgen exposure does not contribute to explaining gender differences in academic interests. However, we find some evidence that the relationship with parental gender socialisation varies by prenatal androgen exposure. A more gender-equal parental division of domestic work is more strongly associated with less gendered academic interests for girls with low prenatal androgen exposure and for boys with medium to high androgen exposure.

Keywords Academic interests · Testosterone · Gender role socialisation · Parental gender division of housework · Father involvement · ALSPAC

Pränatale Androgene und geschlechtsspezifische Sozialisation und ihre Einflüsse auf die schulischen Interessen von Kindern

Zusammenfassung Bisherige Befunde weisen auf geschlechtsspezifische Unterschiede in Studienfächern und dem Interesse an Schulfächern hin. Jungen interessieren sich im Durchschnitt mehr für Mathematik und Mädchen zeigen ein größeres Interesse an Sprachen. Inwieweit diese Unterschiede auf biologische oder auf Umwelteinflüsse zurückzuführen sind, ist noch umstritten. Einerseits legt die Theorie der Gehirnorganisation nahe, dass physiologische und verhaltensbezogene Unterschiede mit dem pränatalen Hormonspiegel zusammenhängen könnten. Andererseits wird aus soziologischer und psychologischer Sicht die Bedeutung der geschlechtsspezifischen Sozialisation betont. In diesem Beitrag werden biologische, psychologische und soziologische Perspektiven kombiniert, um die Entstehung geschlechtsspezifischer akademischer Interessen bei Kindern zu untersuchen.

Die Studie stützt sich auf Daten von 9-jährigen Kindern aus der Avon Longitudinal Study of Parents and Children. Unsere Ergebnisse deuten darauf hin, dass sowohl für Jungen als auch für Mädchen mittlere bis hohe zirkulierende mütterliche Testosteronwerte das Interesse der Kinder an Mathematik im Vergleich zu Englisch erhöhen im Vergleich zu niedrigen Werten. Jedoch variieren die Ergebnisse etwas, je nachdem wie die pränatale Testosteron-Exposition gemessen wird. Da die Verteilungen der pränatalen Androgenspiegel und die Beziehungen zu den Interessen in Mathematik und Englisch für Jungen und Mädchen sehr ähnlich sind, tragen pränatale Androgene nicht zur Erklärung der Geschlechterunterschiede bei den akademischen Interessen bei. Wir finden jedoch Hinweise darauf, dass der Zusammenhang mit der elterlichen Geschlechtersozialisation je nach pränatalem Androgenspiegel variiert. Eine geschlechtergerechtere Aufteilung der Hausarbeit durch die Eltern ist bei

Mädchen mit niedrigem pränatalen Androgenspiegel und bei Jungen mit mittlerem bis hohem Androgenspiegel stärker mit weniger geschlechtsspezifischen schulischen Interessen verbunden.

Schlüsselwörter Akademische Interessen · Testosteron · Geschlechtersozialisation · Geschlechtsspezifische Aufteilung der Hausarbeit · Väterliche Kinderbetreuung · ALSPAC

1 Introduction

Despite some convergence in recent decades, substantial gender differences persist in educational and occupational choices and subsequent earnings (Barone 2011; Bobbitt-Zeher 2007; Charles and Bradley 2009; Hook 2006; Pettit and Hook 2005). Women have made more inroads into traditionally male occupations, especially in professional and managerial fields, than men into traditionally female occupations (England 2010). The stratification theory of gender essentialism argued that young people's choices of fields of study and occupations are influenced by persistent gender essentialist beliefs and increasing self-expressive values (Cech 2013; Charles and Bradley 2009). Another potential explanation for the slower pace of change in men's educational and occupational choices than in women's came from neuroscientific research on biological sex differences. The latter suggested that gender-related behaviours are influenced by genes and physiology and mediated by brain processes (for reviews, see for example Berenbaum and Beltz 2016; Hines 2015). Integrated theoretical models increasingly assumed that environmental and socialisation contexts modify behavioural effects of sex hormones. However, the results of the few existing studies that considered both types of influences challenge notions of continuous change towards more symmetric or androgynous behaviours, as several found significant effects of hormones and found more varied evidence on parental socialisation (e.g. Davis and Risman 2015; Udry 2000; Hines et al. 2002).

Recent evidence suggested that gender stereotypes regarding school subjects were prevalent amongst both students (Favara 2012) and teachers (Kessels 2005). Boys appeared to be more interested in mathematics, and girls appeared to be more interested in language (Evans et al. 2002). These differences increased during children's educational careers, distancing girls from the "hard" sciences (Häussler and Hoffmann 2000; Jones et al. 2000; Labudde et al. 2000), which may have, in turn, affected girls' later occupational choices. Disparities in school subject interests were not fully explained by differences in performance (Ceci and Williams 2010; Hyde and Mertz 2009; Riegle-Crumb et al. 2012). Favara (2012) found that boys and girls who perform equally well in the same subjects frequently choose subjects differently and in accordance with their gender. Previous research has found that liking or enjoying a task or subject was an essential predictor of educational choices, such as track enrolment (Elsworth et al. 1999; van Langen et al. 2007; Lyons 2006). Thus, gender differences in preferences may lead to gender inequalities in educational choices and, consequently, in fields of study and occupations. Hence, school subject interest appears to be the first step that children make towards gender segregation

in education and the labour market. Our research, hence, took a biosocial approach to disentangling how prenatal exposure to free androgens, as well as parent gender role modelling, influenced children's interest in mathematics and English/reading in school.

This study incorporates both physiological and sociological theories and data to continue exploring to what extent hormonal and socialisation processes predict children's gendered academic interests. Our analysis is based on the Avon Longitudinal Study of Parents and Children (ALSPAC), which allows us to measure prenatal exposure to testosterone for a subsample of children, in addition to considering survey information on the parental division of domestic work, fathers' relative involvement in children's daily activities, and mothers' participation in paid work. Specifically, our study investigated how prenatal exposure to testosterone, fathers' relative contribution to housework, and fathers' involvement in children's activities, influenced children's relative (and absolute) interest in mathematics versus English/reading. To do so, we begin by giving an overview of brain organisation theory and existing evidence on the influence that prenatal and early post-natal androgen exposure had on individuals' behaviour and preferences. We then go on to summarise different theoretical perspectives on gender socialisation and related empirical evidence to illustrate how gender role socialisation and, specifically, parental gender role modelling, may be associated with children's development of gender constructions, behaviour, and preferences. The next section introduces the biosocial conceptual model used for the analysis, as well as our predictions regarding effects of prenatal free androgen exposure and parental gender role modelling for both boys and girls. Finally, we detail the methods used, our analytical sample, and the results obtained from its analysis.

2 Theoretical Background and Previous Evidence

2.1 Brain Organisation Theory

Brain organisation theory (Phoenix et al. 1959) stated that prenatal hormone levels during the second trimester of gestation shape the brain development of the foetus. At this point in pregnancy, the testicles of male foetuses begin producing large amounts of testosterone. In female foetuses, androgens are produced by the adrenal glands and the ovaries. Exposure to androgens during this crucial formative phase has long-lasting organisational effects on the brain, as androgens are believed to reflect developments in the organisation of the neural system. Because males and females are exposed to different levels of androgens owing to the development of testes among the former, these effects on organisation vary by sex. Increased prenatal exposure to androgens is believed to not only masculinise the internal and external genitalia but also shape postnatal behaviour in a more stereotypically masculine direction. Sex Hormone Binding Globulin (SHBG) is a protein molecule produced in the liver that binds sex hormones, including testosterone. It transports testosterone in the blood and prevents testosterone molecules from binding to testosterone receptors in the brain, where they exert their behavioural effects. Whereas higher levels of in

utero testosterone are assumed to increase the androgenisation of the foetal brain, a larger amount of in utero SHBG is believed to inhibit it.

The human brain is divided into two hemispheres, the right and the left. These two hemispheres are joined by the corpus callosum, which is a collection of nerve fibres that are situated in the middle of the brain. The lateralisation of brain function refers to the notion that each brain hemisphere oversees different brain functions, which are localised either on the right or the left side of the brain. Whereas the left hemisphere is associated with language functions, the right hemisphere is linked to visuospatial functions. Prenatal exposure to testosterone affects the lateralisation and hemisphere growth of the brain of the foetus. More precisely, callosal theory argued that prenatal testosterone shapes early axon pruning in callosal brain tissue and thus brain lateralisation (Witelson and Nowakowski 1991). Consequently, as exposure to prenatal testosterone increases, so does the lateralisation of the brain. Furthermore, prenatal testosterone exposure appeared to foster the growth of the right hemisphere while decelerating the growth of the left hemisphere (Geschwind and Galaburda 1987). Thus, male foetuses would have both higher lateralisation and larger right brain hemispheres than females owing to unequal exposure to testosterone during the foetal stage. Therefore, the unequal size of these hemispheres as well as the lateralisation of the brain could be a mediating factor in the relationship between sex, brain organisation and sex disparities in interests and abilities.

As Fine (2018) suggested, whereas sex may produce differences in the brain, it is not the basic, determining factor with regard to brain development as it is for the reproductive system. Accordingly, the review by Hyde et al. (2019) highlighted that differences in brain structure between men and women¹ are not sexually dimorphic, and in fact, there is a great overlap between the distributions of the two sexes. Furthermore, Joel et al. (2015) analysed whether there was internal sex consistency on 7–12 brain features that seem to show the largest differences between males and females, such as cortical thickness and connectivity. For each of these characteristics, researchers outlined (1) the structures that were more prevalent in women than in men (female-end form); (2) the structures that were more frequent in men than in women (male-end form); and (3) structures that were similarly prevalent in both males and females (intermediate forms) (Joel et al. 2015; Hyde et al. 2019). Their results showed that “mosaicism”—having at least one structure with a female-end form and at least one structure with a male-end form—was much more frequent than internal consistency (Joel et al. 2015; Hyde et al. 2019). Hence, whereas prenatal testosterone seemed to be associated with brain lateralisation and hemisphere size, there was a great overlap between male and female brains, and “mosaicism” seemed to be more prevalent than internal sex consistency (Joel et al. 2015; Hyde et al. 2019).

¹ We use men/women and male/female as synonyms as we are not able to fully separate the effects of gender and sex. Thus, the terms do not have a “gender” versus “sex” connotation respectively.

2.2 Androgen Exposure and Gendered Behaviour

Empirical evidence on the relationship between prenatal hormone exposure and postnatal behaviour is mixed. On the one hand, there is some evidence that prenatal exposure to androgens correlates with several sex-typed outcomes. First, girls and boys tended to differ in their toy, playmate, and activity preferences (Hines 2010), and prenatal exposure to testosterone has been found to influence these preferences (Alexander 2003; Jadv et al. 2010). Girls with classic Congenital Adrenal Hyperplasia² (CAH), who were exposed to higher-than-normal testosterone levels, have been found to show heightened male-typical play and diminished female-typical play (Berenbaum and Hines 1992; Pasterski et al. 2005). Auyeung et al. (2009) found that foetal testosterone measured directly from the mother's amniotic fluid correlated positively with more masculine play in both boys and girls, whereas two other studies (Grimshaw et al. 1995; Knickmeyer et al. 2005) found no significant relationships. The influence of prenatal exposure to testosterone may extend to overall behaviour, as Hines et al. (2002) found that prenatal testosterone levels in the mother were associated with gender role behaviour in 3.5-year-old girls, meaning that girls with higher exposure prenatally to testosterone exhibited more masculine behaviours. However, no relationship between prenatal testosterone and gendered behaviour was found for boys (Hines et al. 2002). In addition, early postnatal testosterone surges (aka "mini-puberty") have been linked to performance on mental rotation tasks in boys, but not girls, as early as 5–6 months of age (Constantinescu et al. 2018). For girls, by contrast, parents' gender-stereotypical attitudes correlated negatively with mental rotation performance. Hence, the findings of Constantinescu et al. (2018) suggested that whereas early postnatal testosterone surge might have organisational influences on mental rotation performance for boys, parental attitudes might have already influenced their daughter's mental rotation abilities in their first months of life. Based on a small United States (US) sample of 163 white women, Udry (2000) found no significant associations with prenatal testosterone but a positive association of higher prenatal Sex Hormone Binding Globulin (SHBG) levels of mothers with an index of traditional work and care practices, gendered interests and gender role attitudes of their adult daughters (aged 27–30 years). In addition, he found that mother's encouragement of femininity significantly increased the feminine behaviour of their adult daughters with low prenatal exposure to androgen (Udry 2000). Using the same dataset and more complex structural equation models for 342 white women, Davis and Risman (2015) reported a weak positive association of higher prenatal SHBG levels with feminine personality and a strong negative association with masculine personality of these adult women. Nonetheless, the most consistent result in their research was that socialisation appears to be a strong contributor to adult women's gendered behaviour. Finally, because the research of both Udry (2000) and Davis and Risman (2015) focused on a selective sample of white women, it is not possible to assess whether the associations they found would be mirrored in other social groups.

² Congenital adrenal hyperplasia (CAH) is a genetic disorder that causes an increase in adrenal androgen production, beginning at the prenatal stage.

Prenatal testosterone exposure has also been linked to male-typical occupations in females with CAH (Frisén et al. 2009) and to the psychological orientation to things versus people (Beltz et al. 2011). The things versus people scale exhibited substantial sex differences (Su et al. 2009), with boys and men tending to prefer occupations linked to objects or “things”, such as a mechanic, and girls and women more likely to prefer occupations involving work with people, such as a teacher. Using a sample of 9- to 26-year-old individuals with CAH and their same-sex siblings, Beltz et al. (2011) reported that females with CAH were more interested in things relative to people than their unaffected sisters. In addition, variations among females with CAH showed that, as exposure to androgens increased, so did their interest in things relative to people. Males with and without CAH did not seem to significantly differ. In addition, investigating the relative occupational interests of individuals in the sample by analysing their position on the Realistic, Investigative, Artistic, Social, Enterprising, Conventional (RIASEC) scale, which asks individuals about their interest in 64 jobs, Beltz et al. (2011) found that unaffected females expressed more interest in Artistic, Social and Enterprising occupations than unaffected males, whereas the latter seemed to be more interested in Realistic occupations than the former. Females with CAH expressed more interest in Realistic and Investigative occupations than unaffected males, whereas males with and without CAH did not seem to significantly differ (Beltz et al. 2011). Similarly, Weis et al. (2007) found that the second to fourth digit ratio (2D:4D), which is used as a proxy for prenatal androgen exposure, was associated with career interests. In this regard, supposedly higher levels of prenatal testosterone were associated with more masculine career interest scores on the RIASEC scale for both males and females (Weis et al. 2007). Altogether, these results suggest that sex differences in occupational interests may be partly due to the association between prenatal androgen exposure and the orientation to things versus people and occupational interest on the RIASEC scale. Nonetheless, it is important to note that whereas females with CAH showed an increased interest in things rather than people, they did not score as high as males.

Nonetheless, these findings must be taken with caution. First, as Fine (2018) suggested, the scales to measure occupational interests are not free of bias. In this regard, Valian (2014) proposed that the activities that fall under the umbrella of the “things” and “people” dimension may not be free of preconceptions. As a way of illustration, the creation of the subscales that build the “things” dimension could be biased by including activities in which males but not females engaged owing to socialisation, even if both activities would imply a “thing” orientation, such as building a dress versus building a car. Second, meta-analytic reviews of brain research have found little systematic evidence of sex differences in neural structures or related cognitive processing that presumably result from early androgen exposure (Pfannkuche et al. 2008; Sommer et al. 2008). The lack of consistent results could have its origins in the unequal samples and age groups analysed in such articles. Whereas some studies focused on early childhood, others included age ranges from 8 to 44 years. In addition, although some studies directly measured testosterone exposure during pregnancy using the mother's blood or amniotic fluid samples, others used 2D:4D of the participants as a proxy for prenatal testosterone exposure. Metanalyses based on this latter proxy have shown null or mixed findings, and rather

small to moderate associations with outcomes such as athletic talent (Hönekopp and Schuster 2010), aggression and violent behaviour (Hönekopp and Watson 2011; Turanovic et al. 2017), criminal behaviour (Pratt et al. 2016), as well as gender role orientation (Voracek et al. 2011). Hence, 2D:4D has not been validated as a strong indicator of testosterone exposure. Similarly, the large body of research analysing samples of individuals with CAH who, owing to their rare condition, were exposed to higher-than-average levels of testosterone as foetuses also needs to be taken with a grain of salt. This latter approach raises the question of external validity to individuals without CAH, as both the experience and severity of this rare condition may alter biosocial mechanisms.

Given the lack of systematic evidence on how prenatal androgen exposure influences sex differences in brain structures, we sought to examine whether gender differences in children's academic interests were partially explained by varying foetal exposure to maternal circulating androgens.

2.3 Parents as Gender Role Models and Opportunity Enablers

Theoretical perspectives from different social science disciplines (Bisin and Verdier 2001; Bussey and Bandura 1999; Hurrelmann and Bauer 2018; Wood and Eagly 2012) agreed in their view that families are important contexts for gender socialisation. Within the family, children are exposed to beliefs and practices that may be more or less gendered, which is assumed to influence the development of their gender identities, including academic interests (Frome and Eccles 1998; Leaper et al. 2012). Bussey and Bandura's (1999) theory of gender development and differentiation provided the most detailed theoretical account of how parents may shape their children's gendered interests. More precisely, it underlined the importance of role modelling in addition to direct tuition and enactive experience, e.g. praise or disapproval of specific gender-related cognitions and behaviours.

After becoming aware of their assigned sex category, children become increasingly attentive to gender role information (Kohlberg 1966) and learn about stereotypically gendered behaviours, e.g. through observation and modelling (Bandura 1971; Bussey and Bandura 1999). They quickly develop a set of beliefs about gender-typical traits and behaviours and strive to understand the social world around them by searching for gender cues (Kohlberg 1966; Martin and Ruble 2004). When children achieve "gender constancy"—the belief that their gender is unchangeable—they value their gender identity and seek to match their preferences, behaviours and traits to fit sex-typed categories.

Parents act as role models of what is expected of both males and females and create opportunities to engage in less gender-typical activities. They may also discuss their gender beliefs with their children and encourage them to a varying extent to reflect on and challenge gender stereotypes in school environments. These mechanisms are likely to contribute to the emergence of a broad network of gender-related associations that shape children's academic interest. In this regard, more egalitarian families who share domestic work in a less traditional manner are likely to provide their children with a home environment in which gender stereotypes are less likely to be reinforced and more likely to be questioned and challenged by children. Having

fathers who are family oriented and take on a substantial share of childcare is likely to contribute to breaking down the breadwinner–housewife family model, softening gender boundaries and diversifying children's academic interests. Indeed, previous research has found that gender ideologies shape boys' school subject preferences and subsequent educational choices, leading them to more gender-stereotypical choices (van der Vleuten et al. 2016). By spending more equal amounts of time with their mother and father, children in families that share childcare more equally may also have more opportunities to engage in joint leisure and household activities with their mothers and fathers, resulting in less gender-typical exposure during the course of their daily lives and activities.

Several sociologists have argued that biological predispositions, such as gestational androgen exposure, are likely to moderate societal influences on gendered interests and behaviours (Lindsey 1997; Udry 2000; Davis and Risman 2015). Applying a relatively simple design, Udry (2000) found that mothers' encouragement of femininity, retrospectively reported by daughters, was more positively associated with an overall composite index of more traditionally feminine behaviours, interests, attitudes and personalities by daughters at around age 30 among women with lower prenatal exposure to androgens. This result held after controlling for prenatal testosterone and SHBG levels. In addition, they observed that the influence of maternal encouragement of femininity was significantly stronger for women with lower levels of prenatal androgen exposure. For women with high prenatal androgen exposure, socialisation in the form of maternal encouragement of femininity did not seem to correlate with more feminine behaviours by adult daughters. Udry (2000) was unable to examine this relationship for boys but speculated that, owing to boys' higher average prenatal testosterone exposure than that of girls, boys may be less responsive to parental socialisation influences. Based on the same data set but differentiating between feminine and masculine personality as well as between adult social roles and gender ideologies for a larger sample of women, Davis and Risman (2015) found that remembered parental encouragement of masculine behaviours was strongly positively associated with more masculine personalities of adult women, whereas the negative association with feminine personalities was also significant but weaker. These analyses also controlled for prenatal androgen exposure. It is important to note that neither Udry (2000) nor Davis and Risman (2015) were able to analyse the effects of prenatal androgen exposure and parental gender socialisation on males, as their samples were composed of women only.

Our study, hence, tested the relationship of children's gendered academic interests with prenatal androgen exposure and gender socialisation factors as well as whether the former moderated the effect of gender socialisation for both girls and boys.

3 Conceptual Framework

As a framework for understanding children's gendered academic interests, this study highlights the interplay of biological and environmental factors and combines brain organisation theory (Phoenix et al. 1959) with the perspective on gender as a social structure (Risman 2004) and social learning theory (Bandura 1971). In contemporary

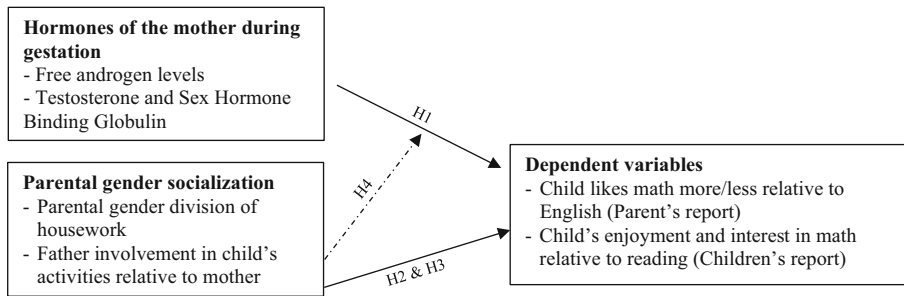


Fig. 1 Conceptual model of interplay between maternal gestational androgens and parental gender socialisation

sociology, gender has been widely understood to be a social structure embedded in the individual, interactional, and institutional dimensions of societies (Risman 2004). Individuals have been argued to “do gender” in everyday interactions, reproducing and renegotiating their gender identities in various contexts (West and Zimmerman 1987). Thus, we expect children’s academic interests to depend on (1) biological predispositions as well as childhood socialisation, (2) how they reproduce and renegotiate gender at the interactional level when facing gender-specific cultural expectations from socialisation agents such as their parents regarding their academic interests and performance, and (3) the broader gender culture individuals are exposed to, namely widespread societal beliefs and their institutional representations (Grunow and Veltkamp 2016; Risman 2004; West and Zimmerman 1987).

We adopted an integrated biosocial perspective of gender development (Hurrelmann and Bauer 2018; Udry 2000; Wood and Eagly 2012; Davis and Risman 2015) to explore the importance of testosterone and gender socialisation on how children develop gendered academic interests (Fig. 1). Socialisation can be understood as the dynamic development of an individual’s self and personality in constant interaction with surrounding social structures. Importantly, individuals were assumed to process socialisation experiences actively and productively (Hurrelmann and Bauer 2018; Bussey and Bandura 1999). This active processing of socialisation experiences is likely to vary by or interact with children’s biological predispositions.

Several reviews suggested that sex differences in things versus people orientation are larger than in most other domains (Archer 2019; Lippa 2010; Su et al. 2009) and manifest in differential attention and interests in everyday life (Graziano et al. 2011; McIntyre and Graziano 2019) as well as varying propensities towards systemising, i.e. seeking patterns and being interested in understanding both natural and technical systems, and towards empathising, i.e. the degree to which people are able to navigate the social world without much effort (e.g. Groen et al. 2018; Baron-Cohen 2003). We assumed that children’s stronger interest in mathematics was driven by greater orientations towards things and systemising (e.g. Baron-Cohen 2003; Svedholm-Häkkinen and Lindeman 2016). This is because mathematics is primarily concerned with the study of abstract concepts, patterns and structures and is frequently used in “things-oriented” occupations, such as engineering fields. Further, stronger interests in language may have been the result of being more people

oriented, as language as a means of communication between people enables interaction with others, sharing thoughts and feelings, and building relationships. Recent psychological studies showed that empathising and systemising relate to academic and vocational interests in the predicted way (Svedholm-Häkkinen and Lindeman 2016; Yang and Barth 2015; Wright et al. 2015). Educational studies, however, also highlighted the relevance of more people-oriented or more things-oriented teaching styles, especially for mathematics (Greer and Mukhopadhyay 2014), possibly suggesting that less people-oriented maths teaching may have contributed to and reinforced some of the sex differences in interests in these subjects.

If, as previous research has shown, androgens increase interest in things- relative to people-oriented activities (Beltz et al. 2011), individuals with greater androgen exposure will show greater interest in mathematics relative to language subjects. This would be because mathematics is closer to “things-oriented” occupations such as those in Science Technology Engineering Mathematics (STEM) fields, whereas language is more related to “people-oriented” occupations and activities. We therefore hypothesise the following:

H 1 Higher levels of prenatal exposure to free testosterone are associated with children's greater relative (and absolute) interest in mathematics over English/reading.

Previous findings by Davis and Risman (2015) suggested that (retrospectively reported) childhood socialisation and mother's encouragement to engage in more “masculine” behaviours were the strongest predictor of masculine personality traits in adulthood among women even after controlling for hormonal effects, whereas Hines et al. (2002) found no significant association with interest in playing and toys among young children. As parents act as role models and create opportunities for their children to engage in more or less gender-typical activities, we believe that a non-traditional division of housework between parents, as well as high involvement of the father relative to the mother in children's activities, softens gender boundaries for their children. Consequently, we assume that children from more egalitarian families and children whose fathers were highly involved in their daily activities relative to their mothers were more likely to develop non-gender-stereotypical academic interests. Therefore, with respect to parental gender role socialisation, we hypothesise that:

H 2 A less traditional parental division of domestic work will increase relative interest in mathematics over English for girls and in English over mathematics for boys.

H 3 Higher involvement of the father relative to the mother in the child's daily activities will increase girls' interest in mathematics over English/reading and boys' interest in English/reading over mathematics.

Nonetheless, previous research has suggested that socialisation may have an unequal effect on children's behaviour and interest owing to prenatal exposure to androgens.

More precisely, Udry (2000) suggested that mothers' encouragement to be feminine had a substantial effect on women with low levels of exposure to androgens, whereas it had very little effect on women with high exposure levels. In addition, the more parents tried to encourage femininity among girls with reduced feminine tendencies, the less successful they were. In other words, gender socialisation was only successful among girls with low androgen exposure, who were already more likely to exhibit reduced masculine behaviours. Based on these results, Udry (2000) concluded that there may be limits to female gender socialisation, and that because males are exposed to even more testosterone, they should be even more resistant to "feminising socialisation" efforts than girls with high exposure to androgens (Udry 2000). However, two other studies (Davis and Risman 2015; Hines et al. 2002) found no moderating relationships of prenatal testosterone exposure and parental gender socialisation factors.

It is yet to be seen whether boys and girls with similar exposure to androgens respond (un)equally to gender socialisation efforts. We thus tested Udry's (2000) argument regarding the moderating effect of prenatal androgen exposure for girls and boys by testing the following hypothesis:

- H 4* A less traditional parental division of housework (*H 4a*) and greater childcare involvement by the father relative to the mother (*H 4b*) increase relative interest in mathematics over English more strongly for girls with lower prenatal androgen exposure and decrease relative interest in mathematics over English more strongly for boys with lower prenatal androgen exposure.

4 Data and Method

To examine these relationships, we drew on the Avon Longitudinal Study of Parents and Children (ALSPAC)³, a birth cohort study of residents of the Avon area in southwest England. The initial dataset consists of over 14,541 pregnancies, with due dates between April 1991 and December 1992. There were 14,676 fetuses, resulting in 14,062 live births and 13,988 children who were alive at 1 year of age (Boyd et al. 2013; Fraser et al. 2013). When the oldest children were approximately 7 years of age, an attempt was made to bolster the initial sample with eligible cases who had failed to join the study originally. As a result, when considering variables collected from the age of 7 onwards (and potentially abstracted from obstetric notes) there are data available for more than the 14,541 pregnancies mentioned above. The number of new pregnancies not in the initial sample (known as phase I enrolment) that are currently represented in the built files and reflecting enrolment status at the age of 24 is 913 (456, 262 and 195 recruited during phases II, III and IV respectively), resulting in an additional 913 children being enrolled. The total sample size for analyses using any data collected after the age of 7 is therefore 15,454 pregnancies, resulting in 15,589 fetuses. Of these, 14,901 were alive at 1 year

³ ALSPAC provides a fully searchable data dictionary and variable search tool on the following website: <http://www.bristol.ac.uk/alspac/researchers/our-data/>.

of age. These children and their families have been intensively observed for over 25 years. Mothers completed yearly questionnaires about themselves until the child reached 12 years of age. Furthermore, questionnaires were completed either by the mother's partner himself or by the mother for her partner until the child reached 12 years of age. Questionnaires about the child were filled in once or twice a year by the mother until the child reached 13 years of age (with the exception of 12-year-olds). The target children also completed regular questionnaires about themselves until they turned 23. Hence, we have data provided by the mother, her partner, and the children themselves. As part of the ALSPAC study, biological samples from about 685 pregnancies were taken. These biological samples included maternal blood samples during pregnancy, from which testosterone levels and SHBG measures were analysed. The analytical sample included all children for whom we had biological data, as well as socialisation information from their parents, and academic interest information for when they were about 9 years old. We selected 9-year-olds because they have already had some experience with the educational system to figure out which school subjects they are more interested in, but have not yet experienced puberty-related hormone surges that may bias our results. Hence, we had complete information for about 300 children (145 males and 155 females).

Both dependent variables—(1) parents' accounts of their child's relative interest in mathematics over English, and (2) children's accounts of whether they are interested, enjoy and look forward to maths/reading work—had a high share of missing values (about 29%). Item non-response to the question on the father's involvement⁴ in children's daily activities relative to the mother was moderate, about 25%. Similarly, the control variable capturing the mother's weekly hours working a paid job had about 27% missing values. By contrast, item non-response was quite low for division of household labour and parental education (2% each). We used multiple imputation by chained equations with ten imputation cycles to impute the missing observations for the individual-level independent variables. Multiple imputation creates numerous different imputed datasets (10 in our case) and combines results from each of them to create an estimate. At the first stage, it builds multiple copies of the dataset, in which the missing values are substituted by imputed values. These "replacing" values are the result of the predictive distributions based on observed data—in our case, all independent variables but prenatal androgen exposure and week of gestation. At the second stage, we fit our model for each of the imputed datasets. In this manner, we obtain estimated associations in each of the imputed datasets. The programme, then, averages the estimates of each of these estimations, and gives us estimated associations among our variables (for more technical information, see Carpenter and Kenward 2013; Rubin 1987). The resulting imputed models comprised a sample of 472 children (232 boys and 240 girls). The independent variables referring to prenatal androgen exposure during pregnancy, as well as week of gestation in which the blood sample was taken, were not imputed. The increase in the sample, thus, is due to the imputation of plausible values among variables, such as the father's relative

⁴ We only considered the answers to the variables for father's involvement in children's activities when the mother's partner was identified as the father of the child.

involvement in the children's activities. Slight differences between the imputed and non-imputed models are discussed in the sensitivity analysis section.

4.1 Dependent Variables

We used measures of children's interests in mathematics versus English to reduce potential bias due to unobserved variation in children's achievement motivation, which may correlate with absolute levels of interest and stem from more privileged parents being more likely to promote their children's academic skills as well as to divide housework and childcare less traditionally. We drew on alternative measures of children's relative interests based on parents' and children's reports, as both may suffer from different types of measurement issues. We did not combine them into a composite index because they correlated only moderately ($p=0.41$).

4.1.1 *Interest in Mathematics Relative to English*

The first measure of children's interest in mathematics relative to English is based on parents' responses regarding whether their child likes mathematics and English at school. Unfortunately, we did not have data on who answered this question. Both variables have three possible responses, which were recoded so that higher values indicate greater interest: (1) does not like it, (2) quite likes it, and (3) likes it a lot. Turning our attention to Table A1 in the Online Appendix, a higher proportion of boys like mathematics "a lot" than girls do, whereas the opposite is true for English. We have left out of the analysis four individuals who answered that their child does not have mathematics or English classes in school. Then, we divided students' interest scores in mathematics by their interest scores in English. Thus, higher values indicate a greater interest in mathematics relative to English. An analysis with an alternative measure (interest in mathematics minus interest in English) yielded virtually the same results. Finally, we z-standardised the resulting variable for the regressions to facilitate interpretation.

4.1.2 *Enjoyment and Interest in Mathematics Relative to Reading*

Based on children's reports, we created a composite variable that captures to what extent the child enjoyed mathematics relative to reading. It is important to note that we used reading rather than the academic subject English because the latter was not available in children's reports, and "reading" was the closest proxy we had. Hence, we drew upon three items capturing whether the child (1) is interested in maths; (2) enjoys doing work in maths and (3) looks forward to mathematics lessons. Children responded to these items on the following scale: (1) not true; (2) mostly untrue; (3) partly true; (4) mostly true; and (5) true. We then applied a polychoric factor analysis ($\alpha=0.93$) to build a combined factor, with higher values indicating more enjoyment and interest in mathematics. Following the same approach, but using children's responses regarding reading enjoyment and interest, we built a factor ($\alpha=0.88$) in which higher values indicate greater enjoyment and interest in reading. We then divided the resulting maths factor by the reading

factor and z-standardised the resulting variable for the regression. Higher values therefore indicate greater interest in mathematics relative to reading.

4.2 Explanatory Variables

4.2.1 *Prenatal Androgen Exposure*

Prenatal measures of testosterone and SHBG were obtained by ALSPAC from the pregnant mother's blood samples and measured in nmol/l. Using both the mother's prenatal levels of testosterone and SHBG, we can create a Free Androgen Index (FAI), which is a ratio used to measure androgen status in humans. The effects of testosterone in the prenatal period are thought of as "organisational", involving more or less permanent effects on the structure of the brain (Phoenix et al. 1959). Hence, FAI is a measure of the pregnant mother's level of testosterone that is free to exert organisational effects on the child's brain. Compared with separate measures of testosterone and SHBG, FAI is supposed to get closer to measuring the freely circulating testosterone and is more parsimonious for including interactions with socialisation factors. However, to facilitate comparability with previous research on biosocial mechanisms, we also present our results on separate measures of testosterone and SHGB levels.

For all three androgen exposure measures, FAI, testosterone and SHGB, we created categorical variables using tertiles as cut-offs indicating (1) low, (2) medium and (3) high levels of prenatal testosterone exposure to allow for non-linear relationships. As Table 1 shows, the distribution of prenatal FAI, testosterone and SHGB among boys and girls is relatively similar, with approximately a third falling into each category.

4.2.2 *Gender*

Gender was measured as the sex category assigned to the child at birth. It takes a value of (1) for males and (0) for females. Hence, females are the reference category in the analysis. We decided to conceptualise this measure as "gender" instead of "sex" to avoid confusion. Whereas sex is generally used to refer to biological predispositions, gender is widely used to refer to the set of social and psychological traits that a society considers appropriate for each sex. As the analysis focuses on 9-year-olds, differences between males and female are likely to be the product of biological predispositions as well as socialisation.

4.2.3 *Father's Housework Contribution Relative to the Mother's*

We drew upon five items to capture parents' division of domestic work. The ALSPAC asked both the mother and her partner who does the following tasks in the family: (1) shopping for groceries, (2) cooking, (3) cleaning, (4) childcare and (5) laundry? There were five possible answer categories: (1) always the mother, (2) mostly the mother, (3) both, (4) mostly her partner and (5) always her partner. We used mothers' answers when the child was about 9 years old and substituted the partner's answers

Table 1 Descriptive statistics

	Boys	Girls
Dependent variables	M (SD)	
Interest in maths relative to English, parent report ^a	1.23 (0.66)	0.916 (0.53)
Interest and enjoyment in maths relative to reading, child report	1.18 (0.82)	0.84 (0.49)
Independent variables	M (SD)	
Housework division	2.19 (0.80)	2.03 (0.69)
Prenatal level of testosterone	3.09 (3.37)	2.88 (1.13)
Prenatal level of Sex Hormone Binding Globulin (SHBG)	259 (127.75)	256 (110.10)
Independent variables	% (N)	
<i>Free Androgen Index</i>		
Low	38 (63)	34 (65)
Medium	29 (48)	36 (59)
High	32 (53)	30 (50)
<i>Testosterone level</i>		
Low	42 (62)	37 (57)
Medium	27 (39)	32 (59)
High	31 (44)	31 (48)
<i>SHBG level</i>		
Low	37 (53)	34 (52)
Medium	29 (42)	37 (58)
High	34 (50)	29 (45)
<i>Father's childcare involvement relative to the mother's</i>		
Low	28 (46)	42 (69)
Medium	36 (58)	37 (61)
High	37 (60)	21 (35)
Control variables	M (SD)	
Gestation week	15.26 (8.1)	16.53 (9.04)
Mother's weekly working hours	17.23 (13.88)	16.99 (14.40)
Control variables	% (N)	
<i>Mother has a partner</i>		
Yes	3 (5)	5 (8)
No	97 (149)	95 (157)
<i>Highest level of parents' education</i>		
CSE	5 (8)	7 (11)
Vocational	5 (8)	4 (7)
0 Level	22 (36)	22 (36)
A level	32 (53)	35 (58)
Degree	36 (59)	32 (53)

CSE Certificate in Secondary Education, SHBG Sex Hormone Binding Globulin

^aHigher values indicate more interest in mathematics relative to English

only when the mother's values were missing. We coded mothers who did not live with a partner, who provided no answers to these questions, as "*always the mother*" and included a dummy variable in our models capturing whether a given mother lives with a partner or not. We then applied a polychoric factor analysis ($\alpha = 0.76$) to construct a combined factor, with higher values indicating a larger share of housework done by the father. For the regressions, we z-standardised the continuous variable. We also tested for non-linear relationships by creating a categorical variable in which (1) indicates a "traditional" and (3) a "non-traditional" division of housework, with (2) falling somewhere in between.

4.2.4 *Father's Relative Involvement in Children's Activities*

To capture the father's relative involvement in children's daily activities, we first used polychoric factor analysis to construct two involvement indicators, one for the mother and one for the father, based on 12 items. These items included shopping, homework, getting ready for school, singing, reading, playing with toys, cuddling, actively playing with the child, going to the park, drawing, cooking food and "making different things". There were five answer categories ranging from (1) never to (5) nearly every day. We only considered these variables when the mother's partner was identified as the father of the child. We constructed two combined factors, with higher values indicating more involvement by the mother and father respectively in these activities. The alphas of the two factors were 0.83 and 0.76 respectively. We applied the scoring coefficients for the father involvement measures to the mother involvement measures to ensure comparability. We then added the two factors to create an index of total involvement in children's activities by both parents. To construct a relative measure of father's involvement in percent, we divided the father's involvement by the total involvement of both parents and multiplied this by 100. To allow for non-linear relationships, we created a categorical variable using tertials as cut-offs in which (1) indicates a "low" (2) a "medium" and (3) a "high" share of the father's involvement in said activities relative to the mother's. It is worth noting that the father's involvement relative to the mother's seems to vary by the gender of the child (Table 1). Hence, a higher proportion of fathers have a high level of relative involvement if the child is a boy (37%) than if the child is a girl (21%).

4.2.5 *Control Variables*

Gestation Week. This variable contains information on the week of pregnancy in which the blood sample from which the testosterone levels were drawn was taken.

Mother Has a Partner. To control for family structure, which would affect housework division, we included a variable that takes a value of (1) if the mother has a male partner, and (0) if the mother does not, when the child is about 9 years old.

Mother's Hours of Paid Work Per Week. The variable contains information regarding the number of hours the mother worked for pay in a normal week when the child

was 8 years old. Mothers who did not engage in paid work were assigned a value of zero hours.

Parental Education. We controlled for the educational qualifications of the parent with highest education at the time the mother was 32 weeks pregnant. When that information was not available at 32 weeks of gestation, we used the information gathered at 18 weeks of gestation. Five categories were distinguished: (1) Certificate of Secondary Education (CSE); (2) vocational qualification; (3) O-levels; (4) A-levels; (5) college degree. As we can see from the data shown in Table 1, nearly two-thirds of the sample had at least A-levels or a college degree.

5 Results

5.1 Modelling Strategy

As our dependent variables are continuous and measured at one time point when the child is about 9 years old, we applied Ordinary Least Squares (OLS) regression models to examine how prenatal exposure to FAI, parental gender role modelling variables and the gender of the child predict children's relative academic interests. As androgen levels fluctuate during pregnancy, we controlled for the gestation week in which the blood sample to measure testosterone levels was taken and examined its interactions with FAI levels. Furthermore, we controlled for whether the mother had a partner, the parents' highest educational credentials at the time of pregnancy, and the mother's hours of paid work in a normal week. As Hypotheses 2 and 3 predict different directions of effects of parental gender role modelling by gender, we ran the models separately for boys and girls. To test Hypothesis 4, we ran a set of interactions between FAI and fathers' childcare involvement as well as housework division, to better understand whether different levels of FAI made children more or less sensitive to gender role modelling influences. Finally, we also ran the models with testosterone and SHBG separately, instead of the composite FAI, to test whether our results were sensitive to the measure selected. All data preparation and analyses were conducted using the statistical programme *Stata Version SE 16.1* (StataCorp, TX, USA).

5.2 Findings

Table 2 presents the results obtained from an OLS regression on interest in mathematics relative to English/reading, reported by both the parents and children, when the children were 9 years of age. This table is quite revealing in several ways. Focusing first on the model with parent reports on the child's academic interest, we see that both boys and girls with high levels of prenatal FAI exposure seemed to show a greater interest in mathematics relative to English than children with low exposure levels. More precisely, for boys, a high level of FAI was associated with a one standard deviation increase in interest in mathematics relative to English, whereas for girls this increase was of nearly 90% of a standard deviation ($p < 0.05$). These

Table 2 Ordinary least squares regression on interest and enjoyment of mathematics relative to English, by child gender

Variables	Parent report ^a		Child report ^a	
	Male	Female	Male	Female
<i>Free Androgen Index (FAI) (Ref. Low)</i>				
Medium	0.689 (0.466)	0.254 (0.355)	0.553 (0.607)	0.121 (0.321)
High	1.003** (0.509)	0.869** (0.389)	0.654 (0.652)	0.120 (0.353)
<i>Father's housework share</i>	0.111 (0.087)	0.049 (0.087)	0.125 (0.111)	0.009 (0.079)
<i>Father's childcare involvement (Ref. Low)</i>				
Medium involvement	-0.135 (0.227)	-0.194 (0.163)	-0.419 (0.297)	0.052 (0.148)
High involvement	-0.115 (0.229)	-0.199 (0.207)	-0.309 (0.303)	0.124 (0.191)
<i>Sample</i>	164	165	145	155
<i>Constant</i>	0.434 (0.680)	-0.433 (0.504)	1.928** (0.918)	-0.358 (0.465)
<i>R-squared</i>	0.115	0.095	0.102	0.117

Controls: Mother has a partner, mother's weekly working hours, highest level of parental education, gestation week in which the blood sample was taken, and an interaction between gestation week and FAI
Standard errors in parentheses; *** $p \leq 0.01$, ** $p < 0.05$, * $p < 0.1$ (two-tailed)

FAI Free Androgen Index

^aHigher values indicate greater interest in maths relative to English/mathematics

differences can be considered quite large. Further analyses of the effects of FAI on absolute interest in mathematics and English reveal that this association seemed to be mainly driven by a positive effect on mathematics interest rather than a negative effect on English interest (Table A2 of the Online Appendix). These results are in line with Hypothesis *H 1*, which stated that higher levels of prenatal exposure to FAI would be associated with children's greater relative and absolute interest in mathematics over English. However, turning our attention to the models based on the children's reports of whether they were interested, enjoyed and looked forward to doing work in mathematics relative to reading, we see that FAI was associated with neither boys' nor girls' relative academic interest. The inconsistency of these results may be because we used interest in "reading" instead of "English" to build the child composite. Thus, whereas children may enjoy reading on different topics—and these topics may reflect their "gendered" interests—they may not enjoy English as a school subject, which may imply that our dependent variables are measuring different outcomes.

The results testing alternative measures of prenatal androgen exposure—levels of testosterone and SHBG separately—are summarised in Table 3. If we focus our attention on the models of academic interests reported by the parent, we can see that prenatal exposure to medium levels of testosterone was associated with a greater interest in mathematics relative to English by 43% ($p < 0.05$) and 33% ($p < 0.10$) of a standard deviation compared with low levels of testosterone for boys and girls

Table 3 Ordinary least squares regression on interest and enjoyment of mathematics relative to English by child gender

Variables	Parent report ^a		Child report ^a	
	Male	Female	Male	Female
<i>Testosterone level (Ref. Low)</i>				
Medium	0.431** (0.212)	0.325* (0.170)	0.614** (0.283)	-0.134 (0.155)
High	0.127 (0.206)	0.252 (0.178)	-0.055 (0.265)	-0.130 (0.156)
<i>Sex Hormone Binding Globulin (SHBG) (Ref. Low)</i>				
Medium	0.062 (0.220)	-0.321* (0.175)	0.088 (0.283)	-0.242 (0.154)
High	-0.233 (0.244)	-0.119 (0.202)	0.025 (0.314)	-0.128 (0.181)
<i>Housework division</i>	0.130 (0.087)	0.033 (0.090)	0.158 (0.109)	-0.000 (0.082)
<i>Father's childcare involvement (Ref. Low)</i>				
Medium involvement	-0.151 (0.225)	-0.197 (0.165)	-0.426 (0.291)	0.099 (0.149)
High involvement	-0.149 (0.230)	-0.192 (0.210)	-0.332 (0.297)	0.204 (0.193)
<i>Sample</i>	164	165	145	155
<i>Constant</i>	0.640 (0.628)	-0.224 (0.466)	1.766 (0.840)	-0.156 (0.423)
<i>R-squared</i>	0.115	0.087	0.134	0.130

Controls: Mother has a partner, mother's weekly working hours, highest level of parental education, SHBG, gestation week in which the blood sample was taken

Standard errors in parentheses; *** $p < 0.001$, ** $p < 0.05$, * $p < 0.1$ (two-tailed)

SHBG Sex Hormone Binding Globulin

^aHigher values indicate greater interest in maths relative to English/mathematics

respectively. In addition, for girls, prenatal exposure to medium rather than low levels of SHBG was associated with a reduced interest in mathematics relative to English by about a third of a standard deviation ($p < 0.10$). When interests were reported by the child instead of the parent we can see that medium levels of prenatal testosterone among boys were associated with a 61% standard deviation increase in interest in mathematics relative to English compared with either low or high levels of testosterone. Based on children's reports, no significant association was found for girls. It is noteworthy that across models, the relationship with prenatal circulating testosterone appeared to be curvilinear. Taken together, the results in Tables 2 and 3 suggest that medium compared with low levels of (circulating) testosterone seemed to be associated with greater interest in mathematics relative to English/reading as reported by the parents and, in the case of boys and testosterone, also as reported by themselves. Thus, again, we found partial support for *H 1*.

Hypotheses *H 2* and *H 3* assumed that a less traditional division of housework and childcare respectively would increase interest in mathematics relative to English for girls and in English relative to maths for boys. Contrary to these expectations, the parental gender division of housework was not significantly associated with

Table 4 Ordinary least squares regression including interaction effects between housework division and prenatal testosterone levels, by child gender

Variables	Parent's reports ^a		Child's reports ^a	
	Male	Female	Male	Female
<i>Testosterone level (T) (Ref. Low)</i>				
Medium	0.422* (0.216)	0.250 (0.170)	0.625** (0.288)	-0.213 (0.155)
High	0.123 (0.208)	-0.234 (0.208)	-0.023 (0.267)	-0.314* (0.173)
<i>Housework division</i>	0.119 (0.116)	0.293** (0.139)	0.262* (0.145)	0.286** (0.128)
<i>Interaction housework division × T (Ref. Low)</i>				
Medium T	-0.14 (0.206)	-0.313* (0.171)	-0.189 (0.281)	-0.404** (0.159)
High T	0.067 (0.184)	-0.538*** (0.212)	-0.237 (0.225)	-0.446** (0.186)
<i>Sample</i>	164	165	145	155
<i>Constant</i>	0.600 (0.678)	-0.319 (0.460)	1633* (0.900)	-0.251 (0.416)
<i>R-squared</i>	0.116	0.127	0.142	0.177

Controls: Mother has a partner, mother's weekly working hours, highest level of parental education, gestation week in which the blood sample was taken, and Sex Hormone Binding Globulin

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ (two-tailed)

SHBG Sex Hormone Binding Globulin, T testosterone

^aHigher values indicate greater interest in maths relative to English/mathematics

children's interests in mathematics relative to English across all models in Tables 2 and 3; thus, H_2 was rejected. Similarly, the father's relative childcare involvement was not significantly associated with children's interest in mathematics relative to English for either boys or girls. This leads us to reject H_3 as well.

In a next step, we included an interaction between the FAI, testosterone and SHBG levels respectively, and the gender division of housework to test H_{4a} , which stated that a less traditional parental division of housework would increase relative interest in mathematics over English/reading more strongly for girls with lower prenatal androgen exposure and decrease relative interest in mathematics over English more strongly for boys with lower prenatal androgen exposure. As shown in Table A3 in the Online Appendix, the interaction between housework division and FAI was not significant for either boys or girls. Similarly, the interactions with SHBG levels never reached statistical significance at the 5% level. However, further tests with (maternal circulating) levels of testosterone (Table 4) showed significant interaction effects for girls. A more egalitarian gender division of housework was positively associated with a stronger interest in mathematics relative to English/reading for girls with low levels of prenatal testosterone, whereas it was mostly not significantly associated with greater relative interest in mathematics for girls who were exposed to medium and high levels of prenatal testosterone. This significant interaction effect was found based on parents' (Fig. A1 in the Online Appendix) and children's (Fig. A2 in the Online Appendix) reports. Hence, whereas we found no support for H_{4a} when we

Table 5 Ordinary least squares regression and interaction effects between father's relative involvement and Free Androgen Index, by gender

Variables	Parent's report ^a		Child's report ^a	
	Male	Female	Male	Female
<i>Free Androgen Index (FAI) (Ref. Low)</i>				
Medium	0.940 (0.599)	0.394 (0.406)	1.398* (0.742)	0.044 (0.371)
High	1.059 (0.573)	1.082** (0.435)	1.232* (0.727)	0.132 (0.011)
<i>Father's childcare involvement (Ref. Low)</i>				
Medium involvement	-0.203 (0.0352)	0.120 (0.270)	0.220 (0.498)	0.039 (0.247)
High involvement	-0.021 (0.352)	0.207 (0.351)	0.613 (0.486)	-0.003 (0.339)
<i>Interaction Father Involvement (FI) × FAI</i>				
Medium FAI × Medium FI	-0.357 (0.545)	-0.445 (0.383)	-0.997 (0.712)	0.078 (0.345)
Medium FAI × High FI	-0.298 (0.554)	0.115 (0.448)	-1.711** (0.699)	0.328 (0.438)
High FAI × Medium FI	-0.054 (0.530)	-0.524 (0.391)	-0.945 (0.694)	-0.028 (0.366)
High FAI × High FI	-0.063 (0.509)	-0.190 (0.0485)	-1.207* (0.676)	0.027 (0.450)
<i>Sample</i>	164	165	145	155
<i>Constant</i>	0.267 (0.745)	-0.641 (0.534)	1.307* (0.957)	-0.365 (0.501)
<i>R-squared</i>	0.117	0.111	0.146	0.122

Controls: Mother has a partner, mother's weekly working hours, highest level of parental education, gestation week in which the blood sample was taken, and an interaction between gestation week and FAI
Standard errors in parentheses; *** $p < 0.001$ ** $p < 0.05$, * $p < 0.1$ (two-tailed)

FAI Free Androgen Index, FI father childcare involvement

^aHigher values indicate greater interest in math relative to English/Mathematics

measured prenatal exposure with FAI and SHGB, we found partial support for girls when we measured prenatal androgen exposure with testosterone.

Hypothesis *H 4b* assumed that greater relative childcare involvement by fathers compared with mothers would increase relative interest in mathematics over English more strongly for girls with lower prenatal androgen exposure and decrease relative interest in mathematics over English more strongly for boys with lower prenatal androgen exposure. As we can see from Table 5, the interaction between prenatal FAI exposure and the father's childcare involvement relative to the mother's was significant for boys but not girls and only when examining children's reports of their interests. Interestingly, once the interaction was included, the main effect of FAI exposure turned significant for boys. This suggests that at low levels of father involvement (the reference category), boys who were exposed to medium or high FAI levels during gestation reported greater relative interest in mathematics versus English than those exposed to low FAI levels. As shown in Fig. 2, for boys with low levels of prenatal FAI exposure, greater relative father involvement did not seem

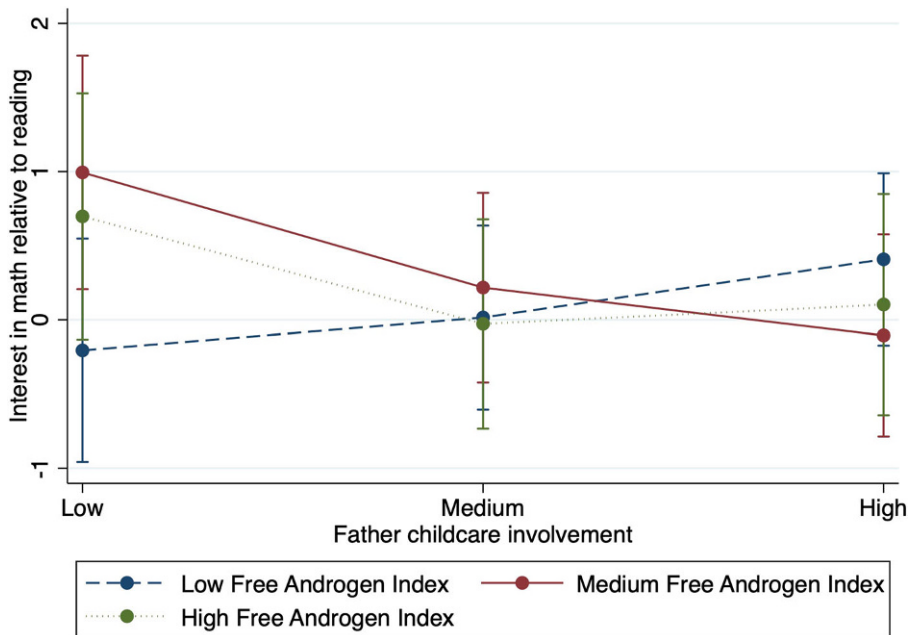


Fig. 2 Interest in mathematics relative to reading (reported by the child), interaction between father's relative childcare involvement and boys' prenatal free androgen exposure

to make a difference to their interest in mathematics versus reading. However, for boys with medium or high levels of FAI exposure, a high level of relative father involvement seemed to decrease their interest in mathematics relative to reading by over a standard deviation more ($b = -1.711$; $p < 0.05$ and $b = -1.207$; $p < 0.1$ for medium and high FAI respectively) than it did for boys with low levels of FAI exposure (Fig. 2). Thus, contrary to Udry's expectations, we found that having a medium/highly involved father decreased interest in maths relative to reading for boys with high and medium testosterone exposure.

Alternative model specifications, including testosterone and SHBG separately, can be found in Table 6. The most interesting aspect of this table is that, contrary to the case of FAI, we found more significant results for girls than for boys. Among girls with medium and high levels of prenatal testosterone levels, a medium/high level of relative father involvement in childcare was less positively associated with their interest in mathematics relative to English/reading (based on parent reports) by about a standard deviation than it was for girls with low prenatal testosterone exposure (see also Fig. A3 in the Online Appendix). If we turn our attention to the academic interests reported by the girls themselves, we can see that, for girls with low prenatal testosterone exposure, having a father who was highly involved in childcare relative to the mother was positively associated with interest in mathematics relative to reading by about one standard deviation. By contrast, the negative and significant interaction effects of roughly the same size with medium and high prenatal testosterone exposure imply that a high level of father involvement did not

Table 6 Ordinary least squares regression including interaction effects between father's relative childcare involvement and testosterone, by child gender

Variables	Parent's reports ^a		Child's reports ^a	
	Male	Female	Male	Female
<i>Testosterone level (T) (Ref. Low)</i>				
Medium	1.059** (0.345)	0.542** (0.253)	1.002* (0.570)	-0.015 (0.240)
High	0.268 (0.387)	0.700*** (0.256)	0.392 (0.527)	0.017 (0.230)
<i>Father Involvement (FI) (Ref. Low)</i>				
Medium	0.658 (0.345)	0.051 (0.244)	-0.142 (0.460)	0.012 (0.214)
High	0.167 (0.340)	0.506 (0.379)	0.032 (0.449)	1.063*** (0.341)
<i>FI × T</i>				
Medium T × Medium FI	-0.595 (0.5534)	-0.051 (0.369)	-0.572 (0.735)	0.235 (0.335)
Medium T × High FI	-1.027* (0.541)	-1.061** (0.466)	-0.425 (0.707)	-1.272*** (0.439)
High T × Medium FI	-0.205 (0.518)	-0.863** (0.373)	-0.380 (0.658)	-0.080 (0.329)
High T × High FI	-0.137 (0.518)	-0.871* (0.504)	-0.810 (0.668)	-0.994** (0.452)
<i>Sample</i>	164	165	145	155
<i>Constant</i>	0.023 (0.740)	-0.688 (0.496)	1.362 (0.991)	-0.464 (0.450)
<i>R-squared</i>	0.139	0.161	0.147	0.208

Controls: Mother has a partner, mother's weekly working hours, highest level of parental education, gestation week in which the blood sample was taken, and Sex Hormone Binding Globulin
Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ (two-tailed)

FI father's childcare involvement, SHBG Sex Hormone Binding Globulin, T testosterone

^aHigher values indicate greater interest in maths relative to English/mathematics

correlate significantly with less gendered interests of children for those who were exposed to medium or high levels of prenatal testosterone (see Fig. A4 in the Online Appendix). Hence, we found partial support for *H4b* for girls that medium and high levels of prenatal testosterone appear to reduce their sensitivity to parental gender socialisation. Similar analyses with interactions of the parental division of childcare with prenatal SHBG levels did not reveal any significant interaction effects. Nonetheless, it is important to acknowledge that the results for moderation effects appeared to vary depending on how we operationalised prenatal androgen exposure.

To understand whether some of the non-significant associations of the parental role modelling variables are due to limited statistical power in the small sample, we tested our measures for gender role socialisation with the larger ALSPAC sample (over 2000 children of each gender) as well, including those without information on prenatal androgen exposure. Thus, we ran the same models without FAI as an explanatory variable and found that whereas a less traditional division of housework was not significantly associated with children's interests based on parental

reports, fathers' childcare involvement was (Table A4, Online Appendix). Thus, having a highly involved father seemed to decrease interest in mathematics relative to English for boys but not girls. Boys with highly involved fathers seemed to be less interested in mathematics relative to English, by 12% of a standard deviation, than boys with fathers with a low level of involvement ($b = -0.124$; $p < 0.05$). However, in this larger ALSPAC sample, children's reports regarding their relative interests showed no significant associations with parental housework division or with father involvement (Table A4). Altogether, these results suggest that the less significant associations in our main models may have been partially driven by the small sample with available information on prenatal androgen exposure.

5.3 Sensitivity Analysis

We conducted multiple imputation models with chained equations to test the robustness of our results. We found a few slight differences. First, the results with parents' accounts of children's relative academic interest showed that whereas in the imputed models, medium but not high levels of FAI among boys were marginally associated with interest in mathematics relative to English, the opposite was the case in the non-imputed models. Second, in the imputed models, medium levels of father involvement exhibited a marginally significant negative association with relative interests as reported by children for boys but not girls, possibly because of the larger sample in the imputed than in the non-imputed models.

6 Discussion

In the literature, increasing attention is being paid to the importance of the prenatal exposure to androgen levels in the development of gendered behaviour and preferences (Alexander 2003; Berenbaum and Hines 1992; Hines et al. 2002; Jadva et al. 2010; Pasterski et al. 2005). Nonetheless, many of these studies have tended to control for rather than actively incorporate societal influences such as gender socialisation and parental role modelling (Hines et al. 2002; Pasterski et al. 2005). Thus, integrating a sociological perspective with biological brain organisation theory, the current study was aimed at shedding light on the interplay between prenatal exposure to androgens and parents' gender role modelling in shaping children's gendered academic interests. This study extends the evidence as to what extent exposure to free androgen prenatally contributes to the emergence of gender differences in relative academic interest in mathematics versus English by age 9. In line with the predictions of brain organisation theory, we found that medium to high levels of prenatal testosterone exposure were associated with children's greater relative interest in mathematics versus English based on parental reports and partly also children's reports. Alternative model specifications show that effects were more significant when gestational androgen exposure is measured in terms of absolute levels of prenatal testosterone followed by the Free Androgen Index (FAI), whereas absolute levels of prenatal Sex Hormone Binding Globulin (SHBG) were mostly not significant. More precisely, children with medium levels of exposure to prenatal testosterone showed

greater interest in mathematics relative to English (reported by the parents) than children with low levels of exposure. These results contrast with Hines et al. (2002), who found higher prenatal testosterone levels to predict more masculine behaviour in 3.5-year-old girls but not boys, and with Beltz et al. (2011), who found higher androgen exposure to increase interest in things relative to people among females with Congenital Adrenal Hyperplasia (CAH) but not males with CAH. Further, girls with prenatal exposure to medium levels of SHBG seemed to show less interest in mathematics relative to English than girls with a low level of exposure. Thus, whereas testosterone exposure increased interest in mathematics relative to English, exposure to SHBG seemed to reduce it. Overall, these results are partly in line with the findings of both Udry's (2000) and Davis and Risman's (2015) research, which found lower prenatal levels of SHGB to predict lower femininity and greater masculinity of adult women in the United States, whereas absolute levels of prenatal testosterone seemed less important.

Our findings generally lend limited support to the gender role modelling hypothesis based on the restricted sample for which we had information on prenatal androgen exposure. Our additional analysis with a larger sample did show some rather small associations between fathers' relative childcare involvement and less gendered academic interests among boys. For girls, we found some support for the argument that parental gender socialisation in terms of the parental division of housework and childcare was only influential among those with low prenatal testosterone levels whereas it seems to have little relevance among girls who were exposed to medium or high testosterone levels during gestation. With alternative measures of testosterone, we found that, among girls with low levels of testosterone, a less traditional gender division of housework was positively associated with a stronger interest in mathematics relative to English/reading. This is in line with Udry's (2000) results, whereas Davis and Risman (2015) did not find any evidence of such a moderation effect. For boys, we found weaker evidence of an interaction effect with FAI, which also points in another direction. Having a highly involved father was negatively associated with interest in mathematics relative to reading for boys with medium and high levels of prenatal free androgens but not for those with low levels. In addition, having a highly involved father did not seem to reduce the gendered academic interest of their daughters with medium/high levels of testosterone. Given our small sample size, these significant interactions are particularly noteworthy, even though they should also be interpreted with some caution. Contrary to Udry's (2000) speculation, our findings suggest that boys are not generally less sensitive to parental gender role modelling than girls and higher levels of prenatal testosterone exposure appeared to reduce the influence of parental gender socialisation for girls but not for boys.

These results are of great practical relevance. Overall, they provide support for the assumption that prenatal androgen exposure may exert a lasting influence on children's academic interests at age 9 years, possibly by increasing their orientation towards things versus people. However, as the distributions of prenatal levels of testosterone, SHGB and the FAI are very similar between boys and girls, the differences between those exposed to low versus medium to high testosterone does not

contribute to explaining differences in gendered academic interests and subsequent educational and occupational field choices.

The quite modest associations of a more gender-equal division of housework and childcare among parents with less gendered academic interests, which are only significant for girls exposed to low levels of prenatal testosterone, suggest that ongoing social change towards more egalitarian division of labour practices in the home is likely to have only small effects and reduces girls' underrepresentation in Science Technology Engineering and Mathematics (STEM) fields only very slowly. However, our results also cast doubt on the assumption that boys in general, or those with higher prenatal testosterone exposure, may be less sensitive to gender socialisation influences. Future research should seek to further investigate possible interdependencies between androgen exposure and socialisation factors for boys as well, to help us to better understand why males are underrepresented in stereotypically feminine fields of study and employment.

There are obvious limitations to our findings. First, our small sample requires us to proceed with caution regarding drawing conclusions. Hence, future research would benefit greatly from larger samples with biological and socialisation data to further explore the potential moderating effects of gender socialisation in translating biological predispositions into academic interests. Furthermore, owing to the limited availability of suitable measures at several time points and important missing data issues, we were unable to test similar relationships with other related outcomes of gendered behaviours or beliefs. Future research should attempt to explore different outcomes of gendered behaviours, interests, and beliefs over several time points to advance our understanding of their development and interrelationships. Furthermore, our measures of parental gender role modelling are likely to affect children's gendered academic interests only very indirectly. Future studies should seek to capture mothers' and fathers' own interests and human capital resources in different subjects or fields, as these might be stronger predictors of children's academic interests, achievement, and educational choices. For instance, fathers who are more family oriented may be less interested in STEM fields themselves and, thus, they may foster that interest to a lower degree than less family-oriented fathers. In addition, it is also possible that mother's prenatal hormone levels affect their own interests and practices, thus making them more prone to engage in a less traditional gender division of housework and childcare. Hence, there may also be an indirect effect of prenatal maternal circulating hormones on offsprings' gendered academic interests. Finally, there may be other hereditary factors that may result in a correlation of mothers' and fathers' interest and involvement in domestic work and their children's interest in maths versus languages. Therefore, the relationships with the parental gender division of labour may not reflect socialisation alone.

This article lays the groundwork for future interdisciplinary research into biological and social influences of gender disparities in academic interests. On the one hand, our empirical findings suggest that we can no longer ignore biological contributions to gendered interests. Yet, prenatal androgen exposure varies similarly across gender groups and appears to exert rather similar effects for most groups of boys and girls and therefore do not provide any clearcut explanations for sustained gender segregation of academic interests and study field choices. On the other hand,

they highlight the relevance of exploring more closely the interdependence of prenatal androgen exposure with socialisation influences, such as father's involvement in housework and childcare activities, for the emergence of gender differences among some groups of children with specific prenatal androgen exposures. These interdependencies may also vary by biological sex and hence more nuanced investigations of more complex biological mechanisms, such as the interplay with hormone levels across different life course phases, would be desirable. Hence, to better understand gender segregation across fields of study, we must advance our understanding of the biosocial mechanisms by which biological predispositions exacerbate or attenuate the influence of parental gender socialisation into academic interests, study field choices and subsequent labour market segregation.

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Declarations

Conflict of interest L. Sánchez Guerrero, P.S. Schober and B. Derntl declare that they have no competing interests.

Ethical standards Ethical approval for the study was obtained from the ALSPAC Ethics and Law Committee and the Local Research Ethics Committees. Consent for biological samples has been collected in accordance with the Human Tissue Act (2004). Informed consent for the use of data collected via questionnaires and clinics was obtained from participants following the recommendations of the ALSPAC Ethics and Law Committee at the time.

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References

- Alexander, Gerianne M. 2003. An Evolutionary Perspective of Sex-Typed Toy Preferences: Pink, Blue, and the Brain. *Archives of Sexual Behavior* 32:7–14.
- Archer, John. 2019. The reality and evolutionary significance of human psychological sex differences. *Biological Reviews* 94:1381–415.

- Auyeung, Bonnie, Simon Baron-Cohen, Emma Ashwi, Rebecca Knickmeyer, Kevin Taylor, Gerald Hackett and Melissa Hines. 2009. Fetal testosterone predicts sexually differentiated childhood behavior in girls and in boys. *Psychological Science* 20:144–48.
- Bandura, Albert. 1971. *Social Learning Theory*. New York: General Learning Press.
- Baron-Cohen, Simon. 2003. *The Essential Difference: Men, Women and the Extreme Male Brain*. New York and London: Penguin/Basic Books.
- Barone, Carlo. 2011. Some Things Never Change: Gender Segregation in Higher Education across Eight Nations and Three Decades. *Sociology of Education* 84(2):157–176.
- Beltz, Adriene M., Jane L. Swanson and Sheri A. Berenbaum. 2011. Gendered occupational interests: Prenatal androgen effects on psychological orientation to Things versus People. *Hormones and Behavior* 60(4):313–317.
- Berenbaum, Sheri A., and Adriene M. Beltz. 2016. How early hormones shape gender development. *Current Opinion in Behavioral Sciences* 7:53–60.
- Berenbaum, Sheri A., and Melissa Hines. 1992. Early Androgens Are Related to Childhood Sex-Typed Toy Preferences. *Psychological Science* 3(3):203–206.
- Bisin, Alberto, and Thierry Verdier. 2001. The Economics of Cultural Transmission and the Dynamics of Preferences. *Journal of Economic Theory* 97(2):298–319.
- Bobbitt-Zeher, Donna. 2007. The Gender Income Gap and the Role of Education. *Sociology of Education* 80(1):1–22.
- Boyd, Andy, Jean Golding, John Macleod, Debbie A. Lawlor, Abigail Fraser, John Henderson, Lynn Molloy, Andy Ness, Susan Ring and George Davey Smith. 2013. Cohort Profile: The 'Children of the 90s'; the index offspring of The Avon Longitudinal Study of Parents and Children (ALSPAC). *International Journal of Epidemiology* 42(1):111–127.
- Bussey, Kay, and Albert Bandura. 1999. Social Cognitive Theory of Gender Development and Differentiation. *Psychological Review* 106(4):676–713.
- Carpenter, James R., and Michael G. Kenward. 2013. *Multiple Imputation and its Application*. Chichester: Wiley.
- Cech, Erin A. 2013. Ideological Wage Inequalities? The Technical/Social Dualism and the Gender Wage Gap in Engineering. *Social Forces* 91(4):1447–1182.
- Ceci, Stephen J., and Wendy M. Williams. 2010. Sex Differences in Math-Intensive Fields. *Current Directions in Psychological Science* 19(5):275–279.
- Charles, Maria, and Karen Bradley. 2009. Indulging Our Gendered Selves? Sex Segregation by Field of Study in 44 Countries. *American Journal of Sociology* 114(4):924–976.
- Constantinescu, Mihaela, David S. Moore, Scott P. Johnson and Melissa Hines. 2018. Early contributions to infants' mental rotation abilities. *Developmental Science* 21(4):1–15.
- Davis, Shannon N., and Barbara J. Risman. 2015. Feminists wrestle with testosterone: Hormones, socialization and cultural interactionism as predictors of women's gendered selves. *Social Science Research* 49:110–125.
- Elsworth, Gerald R., Adrian Harvey-Beavis, John Ainley and Sergio Fabris. 1999. Generic Interests and School Subject Choice. *International Journal of Phytoremediation* 21(1):290–318.
- England, Paula. 2010. The Gender Revolution: Uneven and Stalled. *Gender & Society* 24(2):149–166.
- Evans, E. Margaret, Heidi Schweingruber and Harold W. Stevenson. 2002. Gender Differences in Interest and Knowledge Acquisition: The United States, Taiwan, and Japan. *Sex Roles* 47:153–167.
- Favara, Marta. 2012. The Cost of Acting 'Girly': Gender Stereotypes and Educational Choices. *IZA Discussion Paper* (7037).
- Fine, Cordelia. 2018. *Testosterone Rex: Unmaking the myths of our gendered minds*. London: Icon books.
- Fraser Abigail, Corrie Macdonald-Wallis, Kate Tilling, Andy Boyd, Jean Golding, George Davey Smith, John Henderson, John Macleod, Lynn Molloy, Andy Ness, Susan Ring, Scott M. Nelson and Debbie A. Lawlor. 2013. Cohort Profile: The Avon Longitudinal Study of Parents and Children: ALSPAC mothers cohort. *International Journal of Epidemiology* 42(1):97–110.
- Frisé, Louise, Anna Nordenström, Henrik Falhammar, Helena Filipsson, Gundela Holmdahl, Per Olof Janson, Marja Thorén, Kerstin Hagenfeldt, Anders Möller and Agneta Nordenskjöld. 2009. Gender Role Behavior, Sexuality, and Psychosocial Adaptation in Women with Congenital Adrenal Hyperplasia Due to CYP21A2 Deficiency. *The Journal of Clinical Endocrinology & Metabolism* 94(9):3432–3439.
- Frome, Pamela M., and Jacquelynne S. Eccles. 1998. Parents' influence on children's achievement-related perceptions. *Journal of Personality and Social Psychology* 74(2):435–452.
- Geschwind, Norman, and Albert M. Galaburda. 1987. *Cerebral Lateralization: Biological Mechanisms, Associations, and Pathology*. Cambridge: MIT Press.

- Graziano, William G., Meara M. Habashi and Anna Woodcock. 2011. Exploring and measuring differences in person–thing orientations. *Personality and Individual Differences* 51(1):28–33.
- Greer, B., and S. Mukhopadhyay. 2014. Developing a sociocultural perspective on mathematical engagement: Reframing the problem and supporting teachers' efforts to promote it. *ZDM Mathematics Education* 46(7):1005–1016. (Citation correct? Article not found)
- Grimshaw, Gina M., Gabriel Sitarenios and Jo-Anne K. Finegan. 1995. Mental rotation at 7 years: relations with prenatal testosterone levels and spatial play experiences. *Brain Cognition* 29:85–100.
- Groen, Yvonne, A. Fuernmaier, L. Tucha, J. Koerts, and O. Tucha. 2018. How predictive are sex and empathizing–systemizing cognitive style for entry into the academic areas of social or physical sciences? *Cognitive Processing* 19(1):95–106.
- Grunow, Daniela, and Gerlieke Veltkamp. 2016. Institutions as reference points for parents-to-be in European societies: a theoretical and analytical framework. In *Couples Transitions to Parenthood*, eds. Daniela Grunow and Marie Evertsson, 3–33. Cheltenham: Edward Elgar Publishing
- Häussler, Peter, and Lore Hoffmann. 2000. A curricular frame for physics education: Development, comparison with students' interests, and impact on students' achievement and self-concept. *Science Education* 84(6):689–705.
- Hines, Melissa. 2010. Gendered Behavior Across the Life Span. In *The Handbook of Life-Span Development: Social and Emotional Development*, eds. Richard M. Lerner, Michael E. Lamb, and Alexandra M. Freund, 341–378. Hoboken: Wiley.
- Hines, Melissa. 2015. Gendered Development. In *Handbook of Child Psychology and Developmental Science: Socioemotional processes*, eds. Michael E. Lamb and Richard M. Lerner, 842–887. Hoboken: Wiley.
- Hines, Melissa, Susan Golombok, John Rust, Katie J. Johnston, Jean Golding and the Avon Longitudinal Study of Parents and Children Study Team. 2002. Testosterone during Pregnancy and Gender Role Behavior of Preschool Children: A Longitudinal, Population Study. *Child Development* 73(6):1678–1687.
- Hönekopp, Johannes, and Mirjam Schuster. 2010. A meta-analysis on 2D:4D and athletic prowess: Substantial relationships but neither hand out-predicts the other. *Personality and Individual Differences* 48(1):4–10
- Hönekopp, Johannes, and Steven Watson. 2011. Meta-analysis of the relationship between digit-ratio 2D:4D and aggression. *Personality and Individual Differences* 51(4):381–386.
- Hook, Jennifer L. 2006. Care in Context: Men's Unpaid Work in 20 Countries, 1965–2003. *American Sociological Review* 71(4):639–660.
- Hurrelmann, Klaus, and Ullrich Bauer. 2018. *Socialisation during the Life Course*. London: Routledge.
- Hyde, Janet S., and Janet E. Mertz. 2009. Gender, culture, and mathematics performance. *Proceedings of the National Academy of Sciences of the United States of America* 106(22):8801–8807.
- Hyde, Janet S., Rebecca S. Bigler, Daphna Joel, Charlotte C. Tate and Sari M. van Anders. 2019. The future of sex and gender in psychology: Five challenges to the gender binary. *American Psychologist* 74(2):171–193.
- Jadva, Vasant, Melissa Hines and Susan Golombok. 2010. Infants' Preferences for Toys, Colors, and Shapes: Sex Differences and Similarities. *Archives of Sexual Behavior* 39(6):1261–1273.
- Joel, Daphna, Zohar Berman, Ido Tavor, Nadav Wexler, Olga Gaber, Yaniv Stein, Nisan Shefi, Jared Pool, Sebastian Urchs, Daniel S. Margulies, Franziskus Liem, Jürgen Hänggi, Lutz Jäncke and Yaniv Assaf. 2015. Sex beyond the genitalia: The human brain mosaic. *Proceedings of the National Academy of Sciences of the United States of America* 112(50):15468–15473.
- Jones, M. Gail, Ann Howe and Melissa J. Rua. 2000. Gender differences in students' experiences, interests, and attitudes toward science and scientists. *Science Education* 84(2):180–192.
- Kessels, Ursula. 2005. Fitting into the stereotype: How gender-stereotyped perceptions of prototypic peers relate to liking for school subjects. *European Journal of Psychology of Education* 20(3):309–323.
- Knickmeyer, Rebecca, Simon Baron-Cohen, Peter Raggatt and Kevin Taylor. 2005. Foetal testosterone, social relationships, and restricted interests in children. *Journal of Child Psychology and Psychiatry* 46:198–210.
- Kohlberg, Lawrence A. 1966. A Cognitive-Developmental Analysis of Children's Sex Role Concepts and Attitudes. In *The development of sex differences*, ed. Eleanor E. Maccoby, 82–173. Stanford: Stanford University Press.
- Labudde, Peter, Walter Herzog and Markus P. Neuenschwander. 2000. Girls and physics: teaching and learning strategies tested by classroom interventions in grade 11. *International Journal of Science Education* 22(2):143–157.

- van Langen, Annemarie, Lyset Rekers-Mombarg and Hetty Dekkers. 2007. Sex-related Differences in the Determinants and Process of Science and mathematics Choice in Pre-university Education. *International Journal of Science Education* 28(1):71–94.
- Leaper, Campbell, Timea Farkas and Christia S. Brown. 2012. Adolescent Girls' Experiences and Gender-Related Beliefs in Relation to Their Motivation in Math/Science and English. *Journal of Youth and Adolescence* 41:268–282.
- Lindsey, Linda L. 1997. *Gender Roles: A Sociological Perspective*. Upper Saddle River : Pearson Prentice Hall.
- Lippa, Richard A. 2010. Gender differences in personality and interests: When, where, and why? *Social and Personality Psychology Compass* 4(11):1098–1110.
- Lyons, Terry. 2006. The Puzzle of Falling Enrolments in Physics and Chemistry Courses: Putting Some Pieces Together. *Research in Science Education* 36(3):285–311.
- Martin, Carol L., and Diane Ruble. 2004. Children's Search for Gender Cues: Cognitive Perspectives on Gender Development. *Current Directions in Psychological Science* 13(2):67–70.
- McIntyre, Miranda M., and William G. Graziano. 2019. A snapshot of person and thing orientations: How individual differences in interest manifest in everyday life. *Personality and Individual Differences* 136:160–65.
- Pasterski, Vickie L., Mitchell E. Geffner, Peter Hindmarsh, Charles Brook, Caroline Brain and Melissa Hines. 2005. Prenatal Hormones and Postnatal Socialization by Parents as Determinants of Male-Typical Toy Play in Girls with Congenital Adrenal Hyperplasia. *Child Development* 76(1):264–278.
- Pettit, Becky, and Jennifer Hook. 2005. The Structure of Women's Employment in Comparative Perspective. *Social Forces* 84(2):779–801.
- Pfannkuche, Kristina A., Anke Bouma and Ton G. G. Groothuis. 2008. Does Testosterone Affect Lateralization of Brain and Behaviour? A Meta-Analysis in Humans and Other Animal Species. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364(1519):929–942.
- Phoenix, Charles H., Robert W. Goy, Arnold A. Gerall and William C. Young. 1959. Organizing Action of Prenatally Administered Testosterone Propionate on the Tissues Mediating Mating Behavior in the Female Guinea Pig. *Endocrinology* 65(3):369–382.
- Pratt, Travis C., Jillian J. Turanovic and Francis T. Cullen. 2016. Revisiting the criminological consequences of exposure to fetal testosterone: A meta-analysis of the 2D:4D digit ratio: exposure to fetal testosterone revisited. *Criminology* 54(4):587–620.
- Riegle-Crumb, Catherine, Barbara King, Eric Grodsky and Chandra Muller. 2012. The More Things Change, the More They Stay the Same? Prior Achievement Fails to Explain Gender Inequality in Entry Into STEM College Majors Over Time. *American Educational Research Journal* 49(6):1048–1073.
- Risman, Barbara J. 2004. Gender as a Social Structure: Theory Wrestling with Activism. *Gender and Society* 18(4):429–450.
- Rubin, Donald B. 1987. *Multiple imputation for nonresponse in surveys*. New York: Wiley.
- Sommer, Iris E., André Aleman, Metten Somers, Marco P. Boks and René S. Kahn. 2008. Sex differences in handedness, asymmetry of the Planum Temporale and functional language lateralization. *Brain Research* 1206:76–88.
- Su, Rong, James Rounds and Patrick I. Armstrong. 2009. Men and things, women and people: A meta-analysis of sex differences in interests. *Psychological Bulletin* 135(6):859–884.
- Svedholm-Häkkinen, Annika M., and Marjaana Lindeman. 2016. Testing the Empathizing-Systemizing theory in the general population: Occupations, vocational interests, grades, hobbies, friendship quality, social intelligence, and sex role identity. *Personality and Individual Differences* 90:365–370.
- Turanovic, Jillian J., Travis C. Pratt and Alex R. Piquero. 2017. Exposure to fetal testosterone, aggression, and violent behavior: A meta-analysis of the 2D:4D digit ratio. *Aggression and Violent Behavior* 33:51–61.
- Udry, J. Richard. 2000. Biological Limits of Gender Construction. *American Sociological Review* 65(3):443–457.
- Valian, Virginia. 2014. Interests, gender, and science. *Perspectives on Psychological Science* 9(2):225–230.
- van der Vleuten, Maaike, Eva Jaspers, Ineke Maas and Tanja van der Lippe. 2016. Boys' and girls' educational choices in secondary education. The role of gender ideology. *Educational Studies* 42(2):181–200.
- Voracek, Martin, Jakob Pietschnig, Ingo W. Nader und Stefan Stieger. 2011. Digit ratio (2D:4D) and sex-role orientation: Further evidence and meta-analysis. *Personality and Individual Differences* 51(4):417–422.

- Weis, Sophie E., Annika Firker and Juergen Hennig. 2007. Associations between the second to fourth digit ratio and career interests. *Personality and Individual Differences* 43(3):485–493.
- West, Candace, and Don H. Zimmerman. 1987. Doing Gender. *Gender & Society* 1(2):125–151.
- Witelson, Sandra F., and Richard S. Nowakowski. 1991. Left out axons make men right: A hypothesis for the origin of handedness and functional asymmetry. *Neuropsychologia* 29(4):327–333.
- Wood, Wendy, and Alice H. Eagly. 2012. Biosocial Construction of Sex Differences and Similarities in Behavior. *Advances in Experimental Social Psychology* 46:55–123.
- Wright, Daniel B., Asia A. Eaton and Elin Skagerberg. 2015. Occupational segregation and psychological gender differences: How empathizing and systemizing help explain the distribution of men and women into (some) occupations. *Journal of Research in Personality* 54:30–39.
- Yang, Yang, and Joan M. Barth. 2015. Gender differences in STEM undergraduates' vocational interests: People–thing orientation and goal affordances. *Journal of Vocational Behavior* 91:65–75.

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