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Second to fourth digit ratio and numerical competence in children

Bernhard Fink [a,*], Helen Brookes [b], Nick Neave [b], John T. Manning [c], David C. Geary [d]

[a] *Department for Sociobiology/Anthropology, University of Goettingen, Goettingen, Germany*
[b] *Human Cognitive Neuroscience Unit, School of Psychology and Sport Sciences, Northumbria University, Newcastle upon Tyne, UK*
[c] *Department of Psychology, University of Central Lancashire, Preston, UK*
[d] *Department of Psychological Sciences, University of Missouri, Columbia, USA*

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Abstract

The ratio between the 2nd and 4th fingers (2D:4D)—a potential proxy for prenatal testosterone (T) exposure—shows a sex difference, with males usually having lower mean values; the latter potentially indicates higher prenatal T exposure. We studied relations between 2D:4D and competencies in the domains of counting, number knowledge, and visual-number representation in 73 children aged 6–11 years. Significant negative correlations between numerical performance in all of these areas and right and left hand 2D:4D ratios were found for boys but not girls. To the extent that 2D:4D ratios reflects prenatal exposure to T, the implications are (i) high prenatal T may be associated with better performance on some basic numerical measures for boys, and (ii) prenatal exposure to T may affect boys and girls differently with respect to some numerical competencies.

Keywords: Digit ratio; Number; Counting; Mathematical abilities; Prenatal hormones; Testosterone

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1. Introduction

Children's knowledge of aspects of quantity and basic arithmetic may be an inherent and potentially domain-specific cognitive ability (Dehaene, 1997; Gallistel & Gelman, 1992; Geary, 1995). Comparative studies have revealed basic quantitative abilities in many species, and human infants and very young children show many of the same competencies (e.g., Dehaene, Dehaene-Lambertz, & Cohen, 1998). Neuropsychological and various neuroimaging studies have revealed that processing of different forms of quantitative information and different aspects of arithmetic learning appear to be subserved by distinct neural circuitry (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Delazer et al., 2003; Zorzi, Priftis, & Umiltá, 2002). Dehaene and colleagues proposed a triple-code model whereby three distinct systems of representation (quantity, verbal, and visual) are recruited, dependent upon the demands of the number processing task (Dehaene & Cohen, 1995; Dehaene, Piazza, Pinel, & Cohen, 2003). These systems are located within the left angular gyrus (verbal processing of numbers), posterior superior parietal cortices (spatial and non-spatial attention), and a bilateral segment of the intraparietal sulcus (core number and magnitude processing).

In particular, it has been consistently found that magnitude comparison (Dehaene et al., 1999, 2003; Temple & Posner, 1998), mental number line (Zorzi et al., 2002), and many arithmetic tasks (Chochon, Cohen, van der Moortele, & Dehaene, 1999; Rivera, Reiss, Eckert, & Menon, 2005) engage the bilateral intraparietal sulcus, although other regions are also engaged (e.g., frontal regions associated with working memory; Rivera et al., 2005). The intraparietal sulcus is also active when non-human animals engage in numerical activities (Sawamura, Shima, & Tanji, 2002; Thompson, Mayers, Robertson, & Patterson, 1970), and is anatomically very close to the visual-spatial and posterior spatial-attentional systems. Parietal activation appears greatest in the right hemisphere during some aspects of mental arithmetic (Menon, Rivera, White, Glover, & Reiss, 2000), and number

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[*] Corresponding author. Fax: +49 551 39 7299.
E-mail address: bernhard.fink@ieee.org (B. Fink).

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comparison (Chochon et al., 1999; Stanescu-Cosson et al., 2000), whereas left frontal, angular gyrus, and cingulate cortices are strongly activated during the retrieval of exact arithmetic facts (Dehaene et al., 1999). Regions within the two hemispheres thus appear to be differentially engaged for different quantitative abilities, with a right-hemisphere advantage for tasks requiring more abstract (e.g., relative magnitude) numerical relations and a left-hemisphere advantage for tasks requiring more discrete quantitative information (e.g., Langdon & Warrington, 1997).

Related questions concern the mechanisms that may bias the left- and right-hemispheres to process these different forms of quantitative information. The left-hemispheric bias for retrieval of arithmetic facts appears to be related to the use of language systems for storing and retrieving this form of school-taught arithmetic (Dehaene & Cohen, 1995), and not to an inherent bias of these areas for processing quantitative information (Geary, 1995). The quantitative tasks that preferentially engage areas of the right hemisphere in contrast may tap inherent quantitative abilities, such as magnitude estimation, although it is not yet certain that these areas are distinct from those that subserve other forms of estimation (e.g., luminance; Pinel, Piazza, Le Bihan, & Dehaene, 2004). In any case, it is of theoretical interest because humans appear to display a functional pattern of cerebral lateralization characterized by left hemisphere dominance for verbal processing, and right hemisphere dominance for non-verbal/emotional processing (Geschwind & Galaburda, 1987; Kimura, 1996). Some authors have argued that prenatal testosterone (T) plays a significant role in this lateralization pattern (MacLusky & Naftolin, 1981; Wisniewski, 1998), potentially during a critical period during gestation (around week 16) (Geschwind & Galaburda, 1987).

Human sex differences in brain structure and organization have been observed, and may contribute to sex differences in cognitive abilities (e.g., Aboitiz, Scheibel, & Zaidel, 1992; Goldstein et al., 2001). Although controversial (Bryden, McManus, & Bulman-Fleming, 1994), one mechanism that may link sex differences in brain organization and cognitive abilities was proposed by Geschwind and Galaburda (1987). They proposed that prenatally T slows development of the left hemisphere and facilitates growth of the right hemisphere. On the basis of this theory, it has been predicted that males excel at tasks dependent primarily upon right hemisphere functioning, where females excel in tasks more reliant upon left hemisphere functioning. Some evidence is consistent with this prediction (for review see Halpern, 2000), although the degree of lateralization varies with the task, within sex, and is not always consistent with the prediction (Grön, Wunderlich, Spitzer, Tomczak, & Riepe, 2000). Shaywitz et al. (1995), for instance, found the advantage of females on a language task was related to bilateral activation of Broca's area, as compared to activation of Broca's area only in the left hemisphere for males. In any case, males and females often display different task-dependent hemispheric activation (e.g., Deutsch & Halsey, 1991), and it is possible that these differences are related in part to differential prenatal exposure to T.

For humans, links between prenatal hormone exposure and subsequent cognitive abilities cannot be experimentally established, for ethical reasons. One alternative has been to investigate the correlates of atypical hormone exposure. Congenital adrenal hyperplasia (CAH) is one such condition and results in prenatal exposure to high levels of T. Overall, females with CAH show male levels of performance on some spatial tasks and female levels of performance on others, suggesting prenatal exposure to T affects spatial abilities, but in ways that are not yet fully understood (Cohen-Bendahan, van de Beek, & Berenbaum, 2005; Hines et al., 2003; Resnick, Berenbaum, Gottesman, & Bouchard, 1986). Androgen insensitivity is a second syndrome which results in males being insensitive to the actions of T both pre- and postnatally. These males typically perform poorly on certain spatial tests (Imperato-McGinley, Pichardo, Gautier, Voyer, & Bryden, 1991).

A second alternative has been to correlate hormone levels in umbilical blood cord samples with subsequent cognitive performance. Jacklin, Wilcox, and Maccoby (1988) reported a significant negative relationship between blood androgen levels and spatial ability in girls at age 6, but found no relationship for boys. However, samples of umbilical cord blood may not reflect hormone exposure during the hypothesized critical period of cerebral lateralization (around week 16). Hence, Finegan, Niccols, and Sitarenios (1992) assessed prenatal hormone levels from amniotic fluid during the second trimester; these levels were then correlated with cognitive ability at 4 years of age. In girls, T showed a curvilinear relationship between language comprehension and classification abilities and high T levels were associated with poorer performance on tasks of counting and number facts. Grimshaw, Sitarenios, and Finegan (1995) reported a positive association between amniotic T levels and mental rotation rate in girls but not in boys.

Recently, a third alternative approach has been identified. There is evidence for a sex difference in the ratio between the length of the 2nd digit (the index finger) and the length of the 4th digit (the ring finger) (2D:4D). Males tend to show lower values of 2D:4D than do females and this sex difference is present in children as young as 2 years (Manning, Scutt, Wilson, & Lewis-Jones, 1998). The sex difference may arise from *in utero* concentrations of sex steroids, with 2D:4D being negatively related to prenatal T and positively related to prenatal estradiol (E) (Manning, 2002; Manning et al., 1998). Consistent with this interpretation, Lutchmaya et al. (2004) assessed fetal T and E via amniocentesis and found 2D:4D ratio measured at age 2 was associated with high T in relation to E.

The current study provides the first assessment of the possible relationship between this potential marker of prenatal T exposure and numerical competence in children. We do not focus on specific elements of the triple code model nor on possible hemispheric influences as these should be properly isolated and assessed. Instead we assess finger length ratio and children's performance on a measure of basic numerical abilities (Geary, 1996, 2000). Except for a tendency of girls to use more language-based counting strategies to solve arithmetic problems and boys to have a small advantage on estimation tasks (e.g., Carr & Jessup, 1997; Jordan, Hanich, & Kaplan, 2003), sex differences are not typically found for these basic numerical and arithmetical competencies.

All of the competencies assessed by this measures are foundational for children's mathematical development and thus studies of the sources of individual differences in either the brain systems that subserve the inherent bases or that support the learning of these competencies are of scientific and practical importance. In fact, performance on many of the tasks probably reflects a combination of influences. For instance, children's learning of the mathematical number line and to estimate quantity using this number line appears to emerge from a combination of an inherent understanding of how to estimate quantity and school-based instruction on the formal Hindu-Arabic number system (Geary, 2006; Siegler & Opfer, 2003). Both the inherent knowledge and the school-based learning appear to be dependent on the parietal cortex, particularly of the right hemisphere (Zorzi et al., 2002). At this point, it is not possible to separate inherent and school-based influences on these competencies. Nonetheless, studies of the potential relation between prenatal hormone exposure and these basic competencies will provide foundational information for later, more detailed, research on inherent and school-based influences on the learning of these competencies as well as for a better understanding individual and sex differences in these domains.

2. Method

2.1. Participants

Seventy-three white Caucasian children (35 boys and 38 girls) aged 6–11 years (mean = 9.32, $SD = 1.26$) were recruited from Austria ($N = 39$) and the UK ($N = 34$). All children were right handed as assessed by the Hand Dominance Test (HDT, Steingrüber & Lienert, 1976). None possessed any diagnosis of learning disabilities. Participants took part on a voluntary basis. Parental consent was obtained beforehand and the study was agreed by the ethical committees of the University of Vienna and Northumbria University.

2.2. Measures

2.2.1. Numerical competence

The Number Processing and Calculation in Children (NUCALC) battery (Deloche et al., 1995; von Aster, 2001) was devised to assess very basic numerical abilities in young children that generally do not show sex differences. The battery has been successfully used in several other cross-cultural studies (e.g., Delatolas, von Aster, Willadino-Braga, Meier, & Deloche, 2000; Koumoula et al., 2004), and consists of 11 separate subtests, (1) Counting, (2) Counting backwards, (3) Writing numbers, (4) Mental arithmetic, i.e., addition and subtraction, (5) Reading numbers, (6) Aligning numbers, (7) Oral number comparison, (8) Perception of quantity, (9) Contextual estimation, (10) Problem solving, (11) Written number comparison. A total score (0–118) is based on the sum of raw scores, and scores from three subscales are used to represent (i) number knowledge (subtests $3+5+7+9+10+11$), (ii) counting (subtests $2+4$), and (iii) visual number representation (subtests $6+8$).

2.2.2. Digit ratio

The lengths of the 2nd and 4th digits of the left and right hands were measured from the ventral proximal crease of the digit to the fingertip from the photocopies. Several studies have shown that measurements from photocopies produce similar results compared with other methods (see Manning, 2002). The measurements were made twice with the second measurement made blind to the first. All measurements were made with a digital Vernier caliper (Preisser Products, Germany) measuring to 0.01 mm. Children who reported injuries to the 2nd or 4th digits ($n = 2$) were discarded from the analyses.

Repeated measures ANOVA calculating the ratio (F) between measurement error (the differences between successive measures of 2D:4D) and between-participant differences revealed that between-individual differences were significantly greater than measurement error in 2D:4D (right hand $F(32, 33) = 5.67$, $p < .0001$; left hand $F(32, 33) = 4.93$, $p < .0001$). We concluded that our calculated values of 2D:4D reflected real differences between individuals.

We used unpaired t tests for determining possible sex differences in 2D:4D. A one-sample Kolmogorov–Smirnov goodness-of-fit test (Zar, 1996) revealed that not all variables were normally distributed (i.e., the indices for counting and visual number representation did not). Thus, we used two-tailed Spearman correlation coefficients (ρ) for assessing the relationship between 2D:4D and mathematical performance scores and Mann–Whitney U test to test for sex and country differences on the mathematical abilities scores.

3. Results

3.1. Sex differences

Table 1 reports mean values and standard deviations for age, right and left hand 2D:4D ratios, and numerical performance scores. Mean age of boys was slightly higher than those of girls (Table 1), but this difference was not significant ($t(69) = 1.172$, $p > .05$). In keeping with previous studies (see Manning, 2002), boys' 2D:4D ratio was significantly lower than the girls' ratio in both the right

Table 1
Means and standard deviations (*SD*) for age, mathematical performance scores, and 2D:4D ratios

	Boys and girls ($n = 71$)		Boys ($n = 35$)		Girls ($n = 36$)	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
Age (months)	111.90	15.11	114.09	16.40	109.89	13.75
Total score	96.36	15.82	96.00	18.39	96.68	13.26
Index 1: Number knowledge	62.42	10.86	62.49	12.12	62.37	9.73
Index 2: Counting	20.86	4.89	20.37	5.82	21.32	3.87
Index 3: Visual number representation	11.64	2.41	11.94	2.40	11.37	2.42
2D:4D right hand[a]	.982	0.032	0.969	0.034	0.994	0.026
2D:4D left hand[a]	.978	0.037	0.962	0.037	0.994	0.030

[a] *t* Test significant at $p < .05$.

(boys $x = 0.97 \pm 0.03$, girls $x = 0.99 \pm 0.03$, $t(69) = -3.638$, $p < .01$) and left hand (boys $x = 0.96 \pm 0.04$, girls $x = 0.99 \pm 0.03$, $t(69) = -3.947$, $p < .01$). Although boys and girls demonstrate similar average scores, it can be seen from the standard deviations that the boys show more variability. However, Mann–Whitney *U* tests revealed no significant sex differences on NUCALC total score or on the three subscales (total score, $Z = -.464$, $p = .643$; number knowledge, $Z = -.459$, $p = .646$; counting, $Z = -.300$, $p = .764$; visual number representation, $Z = -1.070$, $p = .285$).

3.2. 2D:4D ratio and numerical competence

Table 2 shows the ρ correlations between total numerical scores, the three subscale scores, and right and left hand 2D:4D ratio for the total sample, and boys and girls separately. Basically, all numerical scores were negatively correlated with 2D:4D ratio in the total sample, and in boys. No significant associations were found in girls.

For boys, significant associations between left and right hand 2D:4D ratio emerged for the numerical total score and the counting subscale. Performance on the number knowledge subscale was also negatively associated with left and right hand 2D:4D ratio but was significant only for the right hand. No significant correlations were found between left and right hand 2D:4D ratio and visual number representation. Further, correlations were found to be higher for right hand digit ratio. In girls, no significant associations were found between 2D:4D and numerical competence scores.

Table 2
Spearman correlation coefficients (ρ) of mathematical performance scores with 2D:4D ratios

	Boys and girls ($n = 71$)	Boys ($n = 35$)	Girls ($n = 36$)
2D:4D right hand			
Total score	−.239*	−.509**	.098
Index 1: Number knowledge	−.165	−.367*	.076
Index 2: Counting	−.265*	−.578**	.032
Index 3: Visual number representation	−.127	−.320	.177
2D:4D left hand			
Total score	−.229	−.356*	−.071
Index 1: Number knowledge	−.166	−.282	−.051
Index 2: Counting	−.242*	−.407*	−.097
Index 3: Visual number representation	−.090	−.143	.087

** $p < .01$, * $p < .05$, two-tailed.

3.3. The effect of age

Additional analyses indicated that age was significantly correlated with total score and scores on some of the subscales. For boys, age was positively correlated with total numerical score ($\rho = .450$, $p < .01$), and scores for number knowledge ($\rho = .469$, $p < .01$), and counting ($\rho = .387$, $p < .05$) subscales. For girls, age was positively correlated with total numerical score ($\rho = .569$, $p < .01$) and scores for number knowledge ($\rho = .446$, $p < .01$) and counting ($\rho = .752$, $p < .01$) subscales.

The 2D:4D of very young children is strongly related to their 2D:4D after a number of years of growth Trivers, Manning, and Jacobson, in press. In addition, sex differences in adult 2D:4D may account for only 5% of the variance in 2D:4D, but patterns of sex difference in children may predict as much as 20% of the variance in adult 2D:4D (McIntyre, Ellison, Lieberman, Demerath, & Towne, 2005). Despite this relative constancy of 2D:4D there is a weak tendency for mean 2D:4D to increase with growth in children (Trivers et al., in press; McIntyre et al., 2005). As a result, the age effects on numerical scores and 2D:4D indicated that age should be controlled in our analyses.

Table 3 presents partial correlations (r_p), holding age constant. These revealed no significant associations between numerical total score and the three subscales and 2D:4D ratios for the total sample. In boys, right hand 2D:4D was significantly negatively correlated with the total score ($r_p = -.432$, $p < .05$), and counting subscale scores ($r_p = -.481$, $p < .05$). The correlation between number knowledge scores and the 2D:4D ratio just failed to reach significance ($r_p = -.332$, $p = .059$), and visual number representation scores remained non-significant ($r_p = -.276$, $p = .120$). Left hand 2D:4D ratio was significantly negatively associated with counting subscale scores ($r_p = -.360$, $p < .05$) but was not significant for the total

Table 3
Partial correlation coefficients (r_p) of mathematical performance scores with 2D:4D ratios adjusted for age

	Boys and girls ($n = 65$)	Boys ($n = 31$)	Girls ($n = 31$)
2D:4D right hand			
Total score	−.161	−.432*	.215
Index 1: Number knowledge	−.116	−.332	.136
Index 2: Counting	−.187	−.481*	.252
Index 3: Visual number representation	−.135	−.277	.149
2D:4D left hand			
Total score	−.104	−.319	.129
Index 1: Number knowledge	−.078	−.243	.070
Index 2: Counting	−.108	−.360*	.153
Index 3: Visual number representation	−.093	−.178	.124

$^{**}p < .01$, $^{*}p < .05$, two-tailed.

score ($r_p = -.319$, $p = .070$). The left hand 2D:4D ratio was not significantly correlated with number knowledge subscale scores ($r_p = -.243$, $p = .173$) and visual number representation subscale scores ($r_p = -.178$, $p = .332$). In girls, correlations between right hand and left hand 2D:4D ratio with the total score and with the three subscale scores were not significant (see Table 3).

3.4. The effect of nationality

As numerical ability scores were assessed from two different nationalities, we controlled for sample differences. Austrian and UK samples were significantly different in age ($T = 6.087$, $p < .01$, Austria: mean age = 10.03, $SD = 0.68$, UK: mean age = 8.56, $SD = 1.30$), total score ($Z = -2.484$, $p < .05$, Austria: mean = 42.76, UK: mean = 30.40), and the counting subscale score ($Z = -3.939$, $p < .01$, Austria: mean = 46.08, UK: mean = 26.59). With one exception (i.e., the association between left hand 2D:4D ratio and the subscale for visual number representation was only close to significance, see below) partial correlations holding age and nationality constant revealed significant associations between numerical abilities scores and right and left hand 2D:4D ratios in boys, but no significant relation was found for girls. The associations for boys were as follows: Right hand 2D:4D: total score, $r_p = -.529$, $p < .05$, number knowledge, $r_p = -.459$, $p < .05$, counting, $r_p = -.499$, $p < .05$, visual number representation, $r_p = -.390$, $p < .05$; Left hand 2D:4D: total score, $r_p = -.467$, $p < .05$, number knowledge, $r_p = -.431$, $p < .05$, counting, $r_p = -.391$, $p < .05$, visual number representation, $r_p = -.343$, $p = .056$. We also found that boys from the UK sample had lower 2D:4D ratios than boys from the Austrian sample (right hand: UK .98, Austria .96, $t(33) = -2.553$, $p < .05$; left hand: UK .982, Austria .943, $t(34) = -3.703$, $p < .05$) whereas no significant difference was found for girls. These country effects in boys were not strong, and the null finding for girls suggests that the country effects were not important.

4. Discussion

The current study was the first to assess the relation between a potential marker of prenatal T, that is the 2D:4D ratio, and numerical competence in children. Our focus was on basic numerical abilities in an attempt to tap potentially inherent numerical skills (Dehaene, 1997; Gallistel & Gelman, 1992), although some school-based influences or a combination of inherent and educational influences are likely as well. In any event, one potential link between prenatal T and individual and sex differences in basic numerical competencies or in the ease of learning these competencies in school is the involvement of various regions of the parietal cortices for processing these forms of numerical information (Dehaene et al., 2003; Geary, 2006; Zorzi et al., 2002), with a potential bias for stronger parietal involvement in the right hemisphere for many of these tasks (Chochon et al., 1999; Menon et al., 2000; Stanescu-Cosson et al., 2000). Prenatal exposure to T may influence the early organization of the right hemisphere (Geschwind & Galaburda, 1987), and result in males becoming more strongly lateralized than females on certain tasks (see Wisniewski, 1998).

If so, then significant relations between the 2D:4D ratio and performance on basic numerical task may be found. In our assessment, we found no significant relationship between 2D:4D ratio and number, counting, or simple numerical abilities in girls, but some significant relationships in boys. Relationships between right and left hand 2D:4D in boys were always negative, i.e., a lower ratio—potentially indicating higher prenatal T—was associated with better performance on the numerical measures, although not all reached statistical significance. However, for boys all of the relationships between 2D:4D and the different quantitative abilities were significant (or near so) once age and nationality was controlled.

Our results differ from studies that have explored relationships between prenatal T and cognitive abilities via direct hormone assays. These studies have in fact demonstrated apparent links between prenatal T and non-verbal cognition in girls but *not* boys. T was assessed via amniotic fluid (early in pregnancy) or via umbilical cord blood samples (Grimshaw et al., 1995; Jacklin et al., 1988). In one study, a negative relationship between T and spatial ability was found (Jacklin et al., 1988), whereas in the other a positive relationship was reported (Grimshaw et al., 1995). More recently, Cohen-Bendahan, Buitelaar, van Goozen, and Cohen-Kettenis (2004) noted that female fetuses sharing the womb with an opposite-sex twin are exposed to higher levels of testosterone. Such twins demonstrated a masculinised pattern of dichotic listening performance compared with same-sex female twins. These studies suggest that prenatal exposure to T may affect the developing female and male brain differently. It has in fact been suggested that developmental periods are different for males and females (Taylor, 1969).

It is, however, difficult to directly compare the results of these previous studies with our results because different cognitive abilities were assessed. The spatial abilities assessed in previous research (Grimshaw et al., 1995; Jacklin et al., 1988) likely engage areas of the parietal cortices, among others, but not the same regions argued to subserve basic numerical competencies (Dehaene et al., 2003). In addition, recent research has shown that correlations between prenatal hormones and maternal serum during pregnancy may not provide a reliable means of assessing the effects of prenatal hormone during periods of neural differentiation, amniotic fluid analysis may be more reliable (van der Beek, Thijssen, Cohen-Kettenis, van Goozen, & Buitelaar, 2004). The latter study (Cohen-Bendahan et al., 2004) assessed auditory-verbal dichotic listening, a skill far removed from those assessed in this current study.

Of greater relevance to our study is Finegan et al.'s (1992) finding of a negative relationship between amniotic fluid T levels taken during the second trimester and performance on counting and number fact tasks: higher levels of T were associated with poorer task performance but only for girls. Once again, direct comparisons are difficult due to the differing methodologies employed. It should be noted that 2D:4D may reflect the actions of testosterone around week 14 of gestation (Garn, Burdi, Babler, & Stinson, 1975) but T levels were measured between weeks 14–20 (median of 16) in the Finegan et al. (1992) study, which could thus have influenced cortical development outside of the same 'window' as that appears to be assessed by 2D:4D.

A finer-grained analysis of counting, number, and simple numerical competencies and 2D:4D will be needed to more fully understand these relationships. For counting, experimental studies and studies of dyscalculia have revealed that this is a multifaceted skill, even in young children (Geary, 2004; Gelman & Gallistel, 1978). Individuals with damage to the right hemisphere sometimes have difficulties with the procedural component of counting, specifically, difficulties in systematically pointing to successive objects as they are enumerated, whereas individuals with damage to the left hemisphere sometimes have difficulties in producing number names (Seron et al., 1991). Even with such difficulties, most of these individuals appear to understand basic counting principles, such as cardinality. Similarly, different component skills with different neural correlates are found for other basic numerical and arithmetic abilities (e.g., Dehaene et al., 1999; Pinel et al., 2004). At this point, our suggestion that prenatal exposure to T, as measured by 2D:4D, may influence individual differences in these domains, at least for boys, and that further study of these potential relations (also with larger samples of children than we had in the present study) using experimental-cognitive measures of basic quantitative abilities is warranted.

The finding of sex differences in 2D:4D is consistent with previous research (Manning, 2002), as is the finding of no sex differences in the areas of number, counting, and basic mathematics (Geary, 1996). The combination of relations between 2D:4D and quantitative abilities for boys but not girls and no sex differences on the quantitative measures suggests that prenatal exposure to T may affect boys and girls differently, as suggested by the Finegan et al. (1992) study, or interact with other hormones to create within-sex differences. These findings are also intriguing given recent evidence that men and women may engage different constellations of brain regions to achieve the same level of performance on at least some cognitive and intelligence measures (Haier, Jung, Yeo, Head, & Alkire, 2005). Our findings, though preliminary, suggest that early exposure to T may have lasting effects on the development of mathematical abilities (Kimura, 1996), particularly in males, and may create sex differences in how numerical problems are solved or how these competencies are learned. At the very least, our results revealed consistent relationships between 2D:4D and basic quantitative abilities in boys and given the potential relation between 2D:4D and prenatal exposure to T, these results are intriguing and merit follow-up studies. Future studies could also focus more closely on possible exposure, taking into account possible differential hemispheric influences in males and females.

5. Uncited reference

Wynn (1995).

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