Sex Dimorphism in Digital Formulae of Children

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KEY WORDS  second-to-fourth digit ratio; 2D:4D; digit ratios; sex dimorphism; sex differences

ABSTRACT  This paper presents results of a study designed to: 1) test for a sex difference in the relative lengths of the finger bones, including the second-to-fourth digit ratio (2D:4D), using left-hand radiographs taken in young children, 2) test whether sex differences can be explained by sex differences in fetal growth, and 3) test the serial stability of sex differences in relative digit lengths, including 2D:4D. Results are presented from 1,060 subjects of the California Child Health and Development Studies. One serial replication at about 9 years old is available from 271 subjects. Results indicate that relative digit lengths are sex-dimorphic in children (Manning et al. [1998] Hum. Reprod. 13:3000–3004, [2004] Early Hum. Dev. 80:161–168). Sex differences in digit length ratios are more pronounced within sibships, where shared family factors are controlled, and are not strongly associated with gross measures of fetal growth, like birth length or weight. Thus, sex differences in the fetal growth of the body are not implicated in sex differences in digital formulae, leaving open the possibility of more direct hormonal and/or genetic causation. However, 2D:4D declined between ages 6–8 in a longitudinal sample, and was a less consistent sex-dimorphic marker than 3D:4D across ethnic groups, suggesting that 3D:4D may be a better marker of perinatal sex differentiation. Prior conflicting findings about 2D:4D may be partly explained by variations in age and ethnicity of populations studied. Am J Phys Anthropol 129:143–150, 2006. ©2005 Wiley-Liss, Inc.

Manning et al. (1998) proposed that digit ratios, and particularly the second-to-fourth digit ratio (2D:4D), can be used as biomarkers of perinatal sex differentiation or masculinization. It has been known for over 100 years that men, on average, have relatively longer ring fingers (fourth digits) than women (Peters et al., 2002b), and this observation was recently rediscovered and extended (Manning et al., 1998; Peters et al., 2002a,b; Rahman and Wilson, 2003; Williams et al., 2000). Wood Jones (1926, p. 75) coined the term digital formula to refer to the relative lengths of the fingers, with a view toward differences between primate species associated with brachial locomotion. Further research identified sex differences in the digital formulae of nonhumans (Brown et al., 2002a; McFadden and Bracht, 2003; Roney et al., 2004) and in human toes (McFadden and Shubel, 2002). Manning et al. (1998) suggested that 2D:4D inversely reflects perinatal testosterone action, which is the key process promoting secondary sex differentiation, as evinced, for example, by the feminine phenotypes of XY-karyotyped women with complete androgen insensitivity syndrome (Wilson, 2001).

More direct evidence for the influence of perinatal androgens on 2D:4D was recently reported. Lutchmaya et al. (2004) showed a relationship between 2D:4D measured in children and testosterone concentration measured in samples of amniotic fluid collected during their gestation. Two groups studying congenital adrenal hyperplasia (CAH), which can entail adrenal hyperandrogenism, reported that children with postnatally treated, nonsalt-wasting forms of CAH have lower, i.e., more masculine, 2D:4D than siblings and nonsibling controls (Brown et al., 2002c; Ötkent et al., 2002). These findings lent considerable support to the hypothesis that 2D:4D is directly affected by perinatal androgens. However, Buck et al. (2003) later reported a failure to replicate this finding in a study employing 2D:4D measured on radiographic films of the left hand to compare CAH-affected females with unaffected males and females. While the mean 2D:4D of affected females was intermediate between unaffected males and females, it was not significantly different from either group. This failure to replicate again draws into question the influence of CAH on the development of 2D:4D.

Nevertheless, the use of 2D:4D as a biomarker of the perinatal effects of testosterone on the brain has become the basis for a small but expanding literature on psychosexual differentiation (Brown et al., 2002b; Csatho et al., 2003; Hall and Love, 2003; Manning, 2002; McIntyre, 2003; Williams et al., 2003). Manning (2002) and others also suggested that 2D:4D be used as an epidemiological risk marker for diseases associated with early androgen exposure or impaired fetal growth (Ronalds et al., 2002) or both, such as risk of breast cancer (Manning and Lenister, 2001) and heart disease (Manning and Bundred, 2000). Pink et al. (2003) and McIntyre et al. (2003) employed 2D:4D to test the proposed role of prenatal

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androgens in the promotion of abdominal adipose deposition, which increases the risk of diseases, including polycystic ovary syndrome and metabolic dysfunction (Abbott et al., 1998, 2002a,b; Eisner et al., 2000, 2003). However, the validity of the 2D:4D measure for these purposes remains insufficiently established.

What evidence would further test the validity of using digital formula measures, especially 2D:4D, as markers of perinatal masculinization? We propose that the following implicit or explicit claims about sex dimorphism in 2D:4D can be more thoroughly tested:

1. The sex difference in adult 2D:4D is largely a remnant of sex differences persisting from the prenatal period, implying that 2D:4D is at least as sex-dimorphic in young children as in adults (Manning et al., 1998, 2004).

2. Sex dimorphism in digital formulae results from the action of androgens in the developing hand itself, and not as an indirect result of sex differences in gross morphology or physiology, especially including the sex differences in general growth that result in boys being born heavier and longer at birth than girls (Hindmarsh et al., 2002), and with different body proportions (Ounsted and Moar, 1987; Ounsted et al., 1986).

With respect to point 2, it is at least possible, given histological evidence, that sex hormones might directly influence the growth of bones in the hand. Sex hormones are known to act directly on bone growth plate tissue through estrogen receptors alpha and beta (Cutler, 1997; Kusec et al., 1998; Nilsson et al., 1999; Weise et al., 2001), via the activity of growth plate aromatase (Oz et al., 2001) in the case of testosterone, and directly through the androgen receptor (Abu et al., 1997). Given that fetal cartilaginous tissues also express sex steroid receptors (Ben-Hur et al., 1997), sex hormones might directly influence the embryonic development of the anlagen in the fingers. This latter influence would occur primarily during the first trimester of gestation, a time of testicular development and rising androgen production levels in the male fetus (Forest, 1990).

We report on the results of a study conducted using subjects of the California Child Health and Development Studies (CHDS) to test claims 1 and 2. The study employs digit length measures collected from left-hand radiographs of 2–10-year-old children, with some additional investigation of serial stability in digital formulae within childhood.

METHODS

Van den Berg and Christanson (1988) reviewed the history and general methods of the California Child Health and Development Studies (CHDS). The CHDS participants discussed in this paper participated in studies of skeletal age which included the collection of a radiograph of the left hand between 2–10 years of age, beginning in 1967. For the first wave of data collection, subjects were selected according to their height at age 5. Among children of European and African descent, a sample of the tallest and shortest 2.5% of children, and a sample of children within 2.5% of the median height, were selected, and in addition, all children of Chinese and Japanese descent, who comprised 5% of the CHDS population, were selected (Sproul and Peritz, 1971). The first wave of data collection was designed to obtain radiographs close to age 5. The age range at time of radiographs for this wave was 4–8 years old, with 54% taken at age 6. A second wave expanded the sample to include a broader age range for children meeting the same criteria (aged 2–10 years), and added a second radiograph collection from a subset of first-wave participants who had been 6 or 7 years old at time of first radiograph, and were 8 or 9 years old at time of second radiograph. An additional 206 participants provided radiographs as part of a later skeletal age study, the results of which were never published. This third wave consisted of a 25% sample of all small-for-gestational-age children (<2,500 g at birth and ≥37 weeks of gestation) and a 25% sample of all premature newborns (<2,500 g and <37 weeks gestation) among children of European and African descent born in the CHDS. Radiographs were taken at ages 3–10 years in this group.

Second, third, and fourth digit lengths (2D, 3D, and 4D) were obtained from radiographs of 1,060 subjects with at least one radiograph collected. Of these, a second, 8–9-year-old radiograph is available from 271 subjects. In total, 27 radiographs were not suitable for digit length measurement: in 24, the digits were not fully extended against the radiographic plate; in two, the digits were cropped at the edge of the plate; and in one, the digits were blurry. As a result, 14 participants in the original skeletal age studies were excluded from the present study.

We include measures from the third digit both because it was simple to include in measures taken from images that were cropped to include the second and fourth digits, and because previous studies showed left-hand 3D:4D to be sex-dimorphic in adults, though less so than 2D:4D (McFadden and Shubel, 2002). We did not include 1D and 5D primarily because these digits, especially 5D, were much more likely to be insufficiently extended in the radiographs, necessitating the exclusion of many more subjects from analyses involving 5D.

All measures were made on digital images of radiographs, using computer software specially written for the task. Radiographs were digitized to a resolution of 1 μm. An author placed four landmarks per digit at: 1) the proximal end of the diaphysis of the proximal phalanx, 2) the distal end of the proximal phalanx, 3) the distal end of the medial phalanx, and 4) the distal end of the distal phalanx. Dots in Figure 1 show the locations of landmarks. The software also measured the three segment lengths in each digit delimited by these landmarks. The nine segment lengths were used in all multivariate analyses, including: principal components analysis, common principal components analysis, and discriminant function analysis. In Figure 1, segment length variables are labeled with the number of the digit followed by “p” for proximal segment, “m” for medial segment, and “d” for distal segment. In addition, the segment lengths from each digit were summed to yield the digit lengths for the second, third, and fourth digits. Digit lengths and scores derived from multivariate analyses were used in simpler hypothesis-testing analyses, including: correlation, regression, group, and paired t-tests. For all analyses, raw, untransformed length measures were employed. To assess interobserver reliability, segment lengths were obtained using the same method from 40 radiographs by a second person after brief instruction. Interobserver correlations of summed digit lengths were high ($r > 0.99$ for each digit).

Other variables used in the present study were collected in earlier phases of the CHDS. Most subjects of the skele-
RESULTS
Sex and ethnic differences in digital formula

We consider the first four components obtained by principal components analysis of the nine segment lengths. The analysis yielded a size component explaining 89.9% of total variance in the segment length measures (Table 1). Inspecting the canonical correlation coefficients in Table 1, one can see that the second component extracted can be described as a proximodistal component, with canonical correlation coefficients generally decreasing from proximal to distal segments. The third component can be described as a medial phalange component, which primarily contrasts the medial and proximal segments. The fourth component can be described as a lateromedial component, with canonical correlations decreasing from the second (lateral) digit to the fourth (medial) digit.

In addition to the descriptive usefulness of principal components, they can also be used to assign scores to each subject, and are thereby related to digit ratios or other measures, and can be compared between the sexes. In order to use principal components scores for these purposes, it is important to ensure that assumptions about the underlying covariance matrix are not violated. Most importantly, we wanted to ensure that principal components extracted from measures of all subjects do not differ from principal components extracted from subgroups of interest in our analyses, namely the different ethnic groups and the two sexes. Flury’s method of common principal components analysis allows for the comparison of different covariance matrices, and their classification as equal, as proportional, as sharing any number of principal components, or as unequal. By this method, at least these first four principal components are shared by each ethnic group and both sexes. For most comparisons, covariance matrices were determined to be proportional, and sharing all principal components (but not equal), including comparisons between the sexes and within ethnic groups, and also comparisons within a sex and among ethnic groups.

In addition, we performed discriminant function analysis to investigate multivariate sex differences, using all nine segment length measures. The method yields a discriminant function which is similar to a principal component both in its underlying assumptions, and in that scores for each subject can be calculated from the function and correlated both to the nine segment lengths from which the function was obtained, and to other variables such as digit ratios. The sex-discriminating function was estimated using the LINDA program (Cavalcanti, 2001) from the nine finger length segments (correlations also shown in Table 1). The chief locus of sex differences is in the fourth distal segment, with males having relatively longer fourth distal segments. However, this pattern seems to result from an overlay of proximodistal sex differences and lateromedial sex differences, in that both more distal phalanges and more medial digit rays are larger in males. The discriminant function yields a 5.9% sex difference, and distinguishes the sexes in all four specified ethnic groups (though substantially less well among children of Chinese descent). The lower discrimination among Chinese children does not reflect reduced sex dimorphism. A sex-discriminating function obtained from only the children of Chinese descent distinguishes the sexes just as well as functions obtained in other ethnic groups, with sex explaining 5–6% of variance in discriminant scores in each group separately. However, the sex-discriminating function obtained from the Chinese group
loads digit segments differently, particularly segments in the second digit. Coefficients on segments in the second digit are lower (more masculine) than in other ethnic groups. Partly as a result of this difference, contrasts of the fourth digit with the third are more sex-dimorphic than are contrasts with the second.

Table 2 shows that, despite their small magnitudes, the proximodistal and interomedia!al components are both sex-different, while the size and medial phalange components do not differ between the sexes. The interomedia!al component is well-approximated by 2D:4D and less so by 3D:4D. However, 3D:4D also weakly captures the proximodistal component, and is more sex-different than 2D:4D (Table 1). The effect sizes of sex differences in the fingers are small, with sex explaining between 1.5% of the variance in the case of 2D:4D and 3.8% of the variance in the case

<table>
<thead>
<tr>
<th>TABLE 1. First four principal components, and sex-discriminating function structure, from nine length measures, with correlations to digit ratios and sex-discriminating function scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 1,060</td>
</tr>
<tr>
<td>2D proximal</td>
</tr>
<tr>
<td>2D medial</td>
</tr>
<tr>
<td>2D distal</td>
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<tr>
<td>3D proximal</td>
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<td>3D medial</td>
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<td>3D distal</td>
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<td>4D proximal</td>
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<tr>
<td>4D medial</td>
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<tr>
<td>4D distal</td>
</tr>
<tr>
<td>Pearson's r (P value)</td>
</tr>
<tr>
<td>2D:4D</td>
</tr>
<tr>
<td>3D:4D</td>
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<tr>
<td>Sex-discriminant scores</td>
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</tbody>
</table>
Sex differences appear similar in all ethnic groups except for the children of Chinese descent, among whom the lateromedial sex differences are of lesser magnitude. The finding of greater sex difference in 3D:4D seems to contradict findings in adults (McFadden and Shubel, 2002). We will discuss this result later.

In two-way ANOVA analyses, lateromedial component scores and 2D:4D vary more than twice as much among ethnic groups as between the sexes, whereas proxiomodistal component scores and especially 3D:4D vary between the sexes but not among ethnic groups (Table 3).

**Comparison of sister’s with brother’s digit ratios**

Included in the sample are 54 sister-brother pairs born of the same mother and concordant for ethnic classification, of whom 27 were both of Chinese descent and 27 were in other groups. The large number of siblings of Chinese descent allows for a more careful investigation of sex differences in this group, while controlling for distributional and other extraneous differences between ethnic groups that might confound or amplify sex differences. Table 4 shows the mean sex differences in digit ratios of “non-Chinese” and “Chinese” sibling pairs. In both cases, paired-sibling sex differences are substantially greater than the group differences reported in Table 2. Sex accounts for between 11–19% of variation in sibling differences. Furthermore, while sex differences in the digits of children of Chinese descent appear small or nonsignificant in the full sample, the emergence of strong sex differences among the subset of sister-brother pairs suggests that similar sex-differentiating processes operate in this group, but are more obscured by extraneous growth factors.

**Influence of fetal and postnatal growth on digital formula**

Among CHDS participants with left-hand radiographs, and as has been long established, the sexes differ in measures of gross fetal but not postnatal growth. Boys weighed 37.96 g more ($P = 0.0059$) and were 9.02 mm longer ($P < 0.0001$) at birth than girls. However, the sexes did not differ substantially in postnatal growth rate, and boys remained only marginally taller at age 5 (by 7.09 mm; $P = 0.0560$). Do sex differences at birth in gross body size mediate the sex difference in relative digit lengths?

Multiple regression analyses were performed to test whether sex differences in 2D:4D and 3D:4D could be explained by prenatal growth variables (Table 5). In each case, model 1 shows the raw sex difference using a dummy variable, with “0” coded as female and “1” coded as male. The coefficient on this variable reflects the difference between boys and girls. Model 2 includes prenatal growth variables. For the most part, growth variables are not associated with digit ratios and do not substantially mediate (or confound) the effect of sex, except perhaps weakly in the case of 3D:4D, which shows a small inverse association with birth length.

### Serial changes in digital formulae

Second radiographs from 271 children taken at 8 or 9 years old were compared with first radiographs taken 2 years earlier to test for longitudinal stability in digit ratios during a period of growth in digit lengths. In the first and second radiographs, both 2D:4D and 3D:4D are serially correlated (2D:4D, Pearson’s $r = 0.71$, $P < 0.0001$; 3D:4D, $r = 0.70$, $P < 0.0001$). However, both ratios also increase serially in both boys and girls: 2D:4D increases by 0.0110 ($P < 0.0001$), and 3D:4D by 0.0064 ($P < 0.0001$) over the course of about 2 years.

The serial increase in relative fourth digit length does not, however, substantially alter sex differences in the digit ratios. Sex differences in 2D:4D from the second radiograph (girls 0.0110 greater, $P = 0.0009$) are similar to sex differences in 2D:4D from the first radiograph (girls 0.0089 greater, $P = 0.0091$). Likewise, sex differences in 3D:4D from the second radiograph (girls 0.0060 greater, $P = 0.0055$) are similar to sex differences in 3D:4D from the first radiograph (girls 0.0066 greater, $P = 0.0032$).

Serial changes are consistent and significant in children of each ethnic group. However, age at collection of radiograph is not cross-sectionally related to either 2D:4D or 3D:4D in the full sample of participants.

**DISCUSSION**

Before a discussion of the implications of our findings, it is worth emphasizing that they apply only to bone measurements of the digits and only to the left hand. Though below we make comparisons with measurements made on the skin surface of the right hand, the validity of such comparisons is not unproblematic, especially given that sex differences are greater in the right hand (McFadden and Shubel, 2002). That said, we can safely presume that 1) sex-differentiating processes in the left hand and right hand are partly shared, and 2) bone measures of the relative digit lengths correspond to, and meaningfully reflect the underlying determinants of, relative digit lengths as measured on the skin surface.

To review, the findings of the present study about sex dimorphism in the digital formulae of children extend many similar findings in adults, and generally support the hypothesis that digital formula is a trait established largely in utero or in infancy. However, our findings also suggest revisions to the prevailing understanding of the development of digital formulae.

1. Boys have a relatively longer fourth finger that girls, whether compared with the second or third finger or

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**TABLE 3. Two-way ANOVA for digit ratios and principal components, by sex and ethnic group**

<table>
<thead>
<tr>
<th></th>
<th>2D:4D F (P)</th>
<th>3D:4D F (P)</th>
<th>Size F (P)</th>
<th>Proximodistal F (P)</th>
<th>Medial phalange F (P)</th>
<th>Lateromedial F (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>7.1 (0.0080)</td>
<td>14.6 (0.0001)</td>
<td>1.0 (0.3083)</td>
<td>6.6 (0.0103)</td>
<td>0.0 (0.8444)</td>
<td>12.2 (0.0005)</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>19.3 (&lt;0.0001)</td>
<td>0.2 (0.9282)</td>
<td>18.6 (&lt;0.0001)</td>
<td>1.7 (0.1514)</td>
<td>11.8 (&lt;0.0001)</td>
<td>22.1 (&lt;0.0001)</td>
</tr>
<tr>
<td>Sex ethnicity</td>
<td>0.8 (0.5060)</td>
<td>0.4 (0.8072)</td>
<td>0.8 (0.5298)</td>
<td>1.1 (0.3704)</td>
<td>0.1 (0.9711)</td>
<td>1.5 (0.2046)</td>
</tr>
</tbody>
</table>

**TABLE 4. Sister-brother paired comparisons**

<table>
<thead>
<tr>
<th></th>
<th>2D:4D</th>
<th>3D:4D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sister-brother</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paired</td>
<td>t (P)</td>
<td></td>
</tr>
<tr>
<td>Non-Chinese pairs (27 pairs)</td>
<td>0.0131</td>
<td>2.40 (0.0238)</td>
</tr>
<tr>
<td>Chinese pairs (27 pairs)</td>
<td>0.0404</td>
<td>1.78 (0.0086)</td>
</tr>
</tbody>
</table>
both. Our analyses show that, among children, comparison with the third finger distinguishes the sexes much better than with the second finger. This finding seems to contradict previous findings about sex differences in digit ratios, namely that 2D:4D is the more sex-dimorphic digit ratio. This contradiction might arise for a number of reasons. For example, the use of longer segments yields measures with less measurement error; partly as a result, 3D:4D is less variable than 2D:4D.

While measurement error is low for digit ratios, the difference in error accounts for part of the difference in effects, and more so when considering children’s small hands. The possibility that additional sex differences arise later, perhaps during puberty, cannot be dismissed. However, the most obvious reason for the overall greater sex difference in 3D:4D is its consistency across ethnic groups, discussed further below. When subjects are ethnically diverse, as in the present sample, 3D:4D may serve as a better proxy for sex differences because variance in 2D:4D is high.

2. Sex differences are composed both of phalangeal effects and digit effects. Among children, the distal phalanx of boys is absolutely, but especially relatively, longer than that of girls. The more medial fourth digit is also relatively longer in boys. As a result, the distal fourth phalanx shows the greatest relative “masculinity,” and the proximal second and third phalanges, the greatest relative “femininity.” By adulthood, men’s hands are globally larger, but relative differences in the size of digits and phalanges may persist. Further research will be need to establish the developmental pattern.

3. Ethnic groups differ substantially in digital formulae. Ethnic differences may confound sex differences, especially when measures describe only the lateromedial component of sex differences, as does 2D:4D. The use of other measures such as 3D:4D might avert this problem.

4. Sex differences in the fetal growth of the body as a whole are not implicated in sex differences in digital formulae, leaving open the possibility of more direct hormonal and/or genetic causation.

5. Sex differences in digital formulae are more pronounced when comparing opposite-sex siblings than when comparing boys and girls as groups, suggesting that, in addition to ethnic differences, other familial factors may be important determinants of 2D:4D that confound (but do not mediate) sex dimorphism. Within-family comparison has the advantage of simultaneously controlling many background factors. As a result, effect sizes of true effects generally increase. Unfortunately, as control operates grossly on many factors, it is difficult to know what particular familial factors play a role in obscuring the sex difference at a population level. Important factors could be genetic growth factors, patterns of sexual development, nutrition, environmental toxins, patterns of activity, or a number of other factors. Alternatively, it may be that unobserved differences between the sample of siblings and the larger sample could bias results toward greater effects of sex. One obvious possibility would be an effect of parity or of the sex of older siblings (as suggested by Williams et al., 2000), tests of which were performed but not discussed in this paper, but which nevertheless showed no effect.

6. The lateral digit, i.e., the second finger, may grow more in children relative to the medial digit, i.e., the fourth finger, causing lateromedial ratios such as 2D:4D and 3D:4D and 2D:3D to increase with age in growing hands. That said, the trend is not detected cross-sectionally in the full data set, and previous studies employed cross-sectional designs. Therefore, we cannot claim that these findings contradict the previous lack of detection of age-related changes in cross-sectional samples (Manning, 2002, p. 15; Manning et al., 2004).

As the 2D:4D measure of Manning (2002) is the measure most widely used to assess digital formulae in recent research, we can best contextualize our findings by comparison with the 2D:4D findings of previous studies. Generally speaking, sex and ethnic group differences in 2D:4D among the CHDS children are similar to previous findings in adults. In particular, children of African descent have lower 2D:4D than children of European descent.

It is interesting to note that in the cross-ethnic comparison reported in Manning et al. (2006), the groups with the lowest 2D:4D ("Jamaicans" and "Finns") were also groups

| Table 5. Effects of early growth on digit ratios (n = 1,029) |
|------------------|------------------|------------------|
| Independent variable | Coef. | Std. coef. | t | P | Coef. | Std. coef. | t | P |
|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Intercept | 0.9090 | — | 798.70 | <0.0001 | 0.9052 | 0.9052 | 66.50 | <0.0001 |
| Sex (0 = girl. 1 = boy) | −0.0063 | −0.1205 | −3.89 | 0.0001 | −0.0064 | −0.1220 | −3.89 | 0.0001 |
| Birth length (m) | 0.0050 | 0.0063 | 0.19 | 0.8482 | 0.0009 | 0.0076 | 0.23 | 0.8157 |
| Birth weight (kg) | 1.0653 | 0.0012 | 0.04 | 0.9694 | 0.0001 | 0.0012 | 0.04 | 0.9694 |

1 Adjusted R² = 0.0145, F = 15.14, P = 0.0001.
2 Adjusted R² = 0.0147, F = 5.08, P = 0.0017.
3 Adjusted R² = 0.0361, F = 14.44, P < 0.0001.
4 Adjusted R² = 0.0406, F = 14.44, P < 0.0001.
of children (Jamaican average age, 7.66 years; Finn average age, 5.29 years). Given our finding of serial increase in 2D:4D among children is from a sample of only 271, with only one serial replication, and requires further tests. If the finding is true, studies measuring digit ratio in children will have to account for the ages of subjects more carefully. In particular, the lack of consistent findings in studies of congenital adrenal hyperplasia might be partly attributable to this problem (cf. Buck et al., 2003, who compared subjects of widely varying age, including young infants).

Most importantly, the findings of this study leave open the possibility that digit ratios, whether 2D:4D or 3D:4D or some other measure capturing relative fourth digit/distal phalange length, could continue to be employed as markers of prenatal masculinization in biological research (though given small effect sizes, not in medical diagnosis). Even if digit ratios in adults could continue to be used to study the effects of androgens in utero, careful study design might call for the use of measures other than 2D:4D, which is both less sex-dimorphic and more confined with ethnicity in the CHDS children than is 3D:4D.

Also, given the importance of background factors other than sex alone in the determination of digital formula (i.e., ethnic and familial background factors, as demonstrated by sibling comparisons), researchers might wish to consider designing studies with paired sibling (or other relative) comparisons rather than group comparisons where possible (cf. Brown et al., 2002b). This could be accomplished by relating sibling differences in digital formulae with sibling differences in the variable of interest. In this study, we compared opposite-sex siblings to investigate sex differences. However, most research into the correlates of digital formulae would focus on differences between same-sex siblings. Far fewer subjects would be needed using a paired-sibling design. Moreover, the need to control for ethnicity could be avoided, allowing for broader participation and increased generality of findings.

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LITERATURE CITED


