Second to fourth digit ratio, body mass index, waist-to-hip ratio, and waist-to-chest ratio: their relationships in heterosexual men and women

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Summary. Background: Prenatal sex steroids have been broadly discussed in terms of their possible effect on brain differentiation, whereas pubertal/adult sex hormones are thought to be the main regulators of sexually dimorphic physical features in males and females. Assessing prenatal steroid exposure has previously been difficult but evidence now suggests that finger length ratio may provide a ‘window’ into prenatal hormone exposure. The length of the second digit (the index finger) relative to the length of the fourth digit (the ring finger) is sexually dimorphic as males have a lower second to fourth digit ratio (2D:4D). The sexual dimorphism is determined as early as the 14th week of fetal life, and remains unchanged at puberty. There is evidence that sex differences in 2D:4D arise from in utero concentrations of sex steroids, with a low 2D:4D (male typical ratio) being positively related to prenatal testosterone, while a high 2D:4D (female typical ratio) is positively associated with prenatal oestrogen.

Aim: The studied aimed to determine whether, and to what extent, adult sexually dimorphic physical traits, which are largely determined at puberty, relate to traits that are largely determined in utero. This work examined the relationship between three sexually dimorphic traits—body mass index (BMI), waist-to-hip ratio (WHR) and waist-to-chest ratio (WCR)—and digit ratio.

Participants and methods: BMI, WHR and WCR were assessed in 30 heterosexual male and 50 heterosexual female participants by recording their body height, weight, and measuring their waist, hip and chest circumference. Digit lengths of the second and fourth fingers were measured from photocopies of the ventral surface of the hand and by actual finger measurements.

Results: Digit ratio was found to be significantly lower in men than in women. Significant negative correlations were found between female’s left and right hand 2D:4D, waist and hip circumference, and WCR. In males, BMI was found to be positively related to digit ratio but remained significant only for left hand 2D:4D. Generally, the relationships were stronger for females than for males. Although not all relationships were found to be significant, they were in accord with our predictions.

Conclusion: In addition to an activational effect of sex hormones at puberty, the present data suggest an early organizational effect of sex hormones through the association between indices of female body shape, male BMI, and human finger length patterns.

1. Introduction

In general, females have twice as much body fat as males and this is distributed differently around the body. Body fat distribution is sexually dimorphic, and while the dimorphism in body fat is minimal in infancy, childhood and old age, it is maximal during early reproductive life mediated by sex steroids in combination with heritable genetic factors (Nelson et al. 1999). During puberty, males deposit adipose (and also muscle) tissue around the upper body whilst females deposit adipose tissue around the thighs and buttocks. This distribution of body fat is thought to signal

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the ratio of pubertal/adult oestrogen to testosterone, since the predominance of oestrogen at puberty produces a typical female body shape (gynoid), while the predominance of testosterone produces a typical male (android) body shape (Bjorntrop 1997).

The main reason for the stability of sexual dimorphism of body mass index (BMI), waist-to-hip ratio (WHR) and waist-to-chest ratio (WCR) is the sex-hormone profile of an individual. For example, low WHR in women is typically associated with high levels of circulating oestrogens, whereas high WHR is correlated with high levels of circulating testosterone (Evans et al. 1983). WHR in females appears to be directly linked to health and fertility as it has been shown to be an accurate predictor of risk for various diseases (e.g. Singh 1994, Abbott et al. 2002). Moreover, females with an optimal WHR produce more offspring and become pregnant more rapidly when receiving artificial insemination (Singh and Zambarano 1997). Drawings of female figures with a WHR of around 0.7 are rated as being more healthy and fertile (Singh 1993) though this is not always reported (Furnham et al. 1997). Some recent studies have, however, suggested that BMI might be equally or more closely related to female fertility, attractiveness and health (Tovée et al. 1998). A BMI of around 19 is associated with better health and higher reproductive capability (Willett et al. 1995, Wang et al. 2000).

Evidence for exogenous sex hormone administration on body fat distribution can be observed in transsexual men and women. Men that were treated with oestrogen developed a gynoid fat distribution, whereas women treated with testosterone developed an android fat distribution (Vague et al. 1984). Studies have shown that in normal males, ageing is accompanied by decreasing testosterone levels, decreasing lean body mass and increasing abdominal fat deposition. Testosterone supplementation in elderly males and in healthy eugonadal men decreases WHR and increases lean body mass (Rebuffe-Scrive et al. 1991, Vermeulen et al. 1999).

It is commonly accepted that pubertal/adult sex hormones are the main regulators of sexually dimorphic physical features. However, some studies have suggested that early (prenatal) hormones may also significantly influence the development of somatic asymmetries. Sexually dimorphic physical traits are mainly interpreted as a consequence of pubertal hormone levels but at least part of the variance in these traits may depend upon in utero masculinizing or defeminizing effects. However, the interplay between organizational and activational effects of hormones is still a matter of debate. Hence are, and to what extent, sexually dimorphic traits, largely determined at puberty, related to traits that are largely determined in utero?

One physical feature that has been suggested to relate to prenatal hormone levels is the ratio between the length of the second digit (the index finger) and the length of the fourth digit (the ring finger). There is accumulating evidence that this 2D:4D ratio is sexually dimorphic and is largely determined prenatally (Manning 2002). Thus males tend to show lower values of 2D:4D than do females, i.e. males have on average longer fourth digits relative to their second than females (Phelps 1952, Manning et al. 1998). Relative finger lengths are determined before birth (Garn et al. 1975), the sex difference in 2D:4D is present in children as young as 2 years (Manning et al. 1998), and sex differences in 2D:4D are robust across a number of ethnic groups and races (Manning 2002).

The sexual dimorphism in 2D:4D has been known for many years (e.g. see Baker 1888). However, it has only recently been suggested that sex differences in 2D:4D arise from in utero concentrations of sex steroids, with 2D:4D negatively related to
prenatal testosterone and positively associated with prenatal oestrogen (Manning et al. 1998). The evidence for these relationships with sex hormones is as follows: (i) some sexually dimorphic traits with an excess of males are associated with low 2D:4D ratios (left-handedness (Manning et al. 2000); autism (Manning et al. 2001); good visuo-spatial ability (Manning and Taylor 2001); fast running speed (Manning and Pickup 1998)). Other dimorphic traits with an excess of females are associated with high 2D:4D ratios (good verbal fluency and breast cancer (Manning 2002)); (ii) mothers with high WHR, which is associated with high testosterone and low oestrogen, tend to have children with low 2D:4D ratios (Manning et al. 1999); (iii) children with congenital adrenal hyperplasia (CAH), a condition associated with high prenatal androgens, have lower 2D:4D ratios than controls (Okten et al. 2002); (iv) mothers with low 2D:4D tend to have children with low 2D:4D ratio and their children have high concentrations of testosterone in their amniotic fluid (Manning 2002).

If the sexual dimorphism in 2D:4D ratio is largely determined in utero, what is its relationship with other sexually dimorphic traits, which are largely determined at puberty? This question is the focus of the current study. Three such sexually dimorphic traits: BMI (kg m\(^{-2}\)), WHR and WCR, were examined. We related these variables to right hand 2D:4D and left hand 2D:4D. The 2D:4D ratios are thought to be negatively associated with prenatal testosterone and positively with prenatal oestrogen. Our predictions were that the androgenized forms of the digit ratios (low 2D:4D ratio) would be negatively associated with androgenized forms of BMI, WHR and WCR (high BMI, WHR and WCR).

2. Methods
2.1. Participants and measures

Participants were 50 males (mean age = 22.47, SD = 4.88) and 70 females (mean age = 22.90, SD = 4.25) recruited from the University of Vienna, Austria (n = 58) and Northumbria University, UK (n = 62). Height and body weight were recorded. Chest, hip, and waist circumferences of each participant were measured using a tape measure. In accordance with ethical guidelines a female investigator took measurements from female participants, and a male investigator took measurements from male participants.

Photocopies were made of the ventral surface of the hand. The participants were asked to place their hands palm down on the centre of the glass plate of the photocopier and one photocopy per hand was made. Care was taken to ensure that details of major creases could be seen on the hands. When quality was poor a second photocopy was made. We measured the lengths of the second and fourth digits of the left and right hands from the ventral proximal crease of the digit to the tip from the photocopies. Where there was a band of creases at the base of the digit, we measured from the most proximal of these. For 120 right and left hands, the second and fourth digits were measured directly from the hand and from the photocopies in order to establish repeatabilities. All measurements were made with a digital Vernier calliper (Preisser Products, Germany) measuring to 0.01 mm. Those participants who reported injuries to the second or fourth digits were discarded from the analyses, as were participants who identified themselves as homosexual or bisexual so that our final sample number was 30 males and 50 females.

Comparisons between 2D:4D ratios calculated from measurements made on the hand and those made from photocopies gave an intra-class correlation coefficient of
We used repeated measures ANOVA to calculate the ratio \( F \) between measurement error (the differences between successive measures of 2D:4D) and between-participant differences. We found that between-individual differences were significantly greater than measurement error in 2D:4D (right hand \( F = 5.14, p = 0.0001 \); left hand \( F = 4.00, p = 0.0001 \)). We concluded that our calculated values of 2D:4D reflected real differences between individuals.

We used unpaired \( t \)-tests for determining possible group differences in 2D:4D. If not reported otherwise, one-tailed Pearson correlation coefficients were used for assessing the relationship between 2D:4D and anthropometric indices.

### 3. Results

Means and standard errors for age, height, weight, chest, waist and hip circumferences as well as the WHR, WCR and BMI of the final sample are reported in table 1. There were no significant sex differences in age and hip circumference (unpaired \( t \)-tests, age: \( t = -0.417, p = 0.678 \); hip: \( t = 0.113, p = 0.910 \)). As expected with other traits of absolute size there were significantly larger values for males compared with females (height: \( t = 11.06, p = 0.000 \); weight: \( t = 8.44, p = 0.000 \); chest: \( t = 5.01, p = 0.000 \); waist: \( t = 5.57, p = 0.000 \)). The body ratios of BMI, WHR and WCR all showed significantly larger values for males compared with females (BMI: \( t = 3.22, p = 0.002 \); WHR: \( t = 7.23, p = 0.000 \); WCR: \( t = 2.77, p = 0.07 \)).

In accordance with previous reports (Manning 2002), male 2D:4D ratio was significantly lower in both hands than the female ratio (unpaired \( t \)-tests, 2D:4D right hand: males \( x = 0.95 \pm 0.03 \), females \( x = 0.98 \pm 0.03 \), \( t = -4.102, p = 0.000 \); 2D:4D left hand, males \( x = 0.96 \pm 0.03 \), females \( x = 0.98 \pm 0.03 \), \( t = -3.451, p = 0.001 \)). Male and female regression of 2D:4D right hand, or 2D:4D left hand on age, weight and height did not give significant relationships:

- **Age**: males, right hand, \( \beta = -0.154, F = 0.685, p = 0.415 \); males left hand, \( \beta = -0.046, F = 0.059, p = 0.810 \); females, right hand, \( \beta = 0.010, F = 0.005, p = 0.942 \); females left hand, \( \beta = -0.030, F = 0.043, p = 0.837 \).
- **Height**: males, right hand, \( \beta = -0.135, F = 0.516, p = 0.478 \); males left hand, \( \beta = -0.334, F = 3.526, p = 0.071 \); females, right hand, \( \beta = 0.170, F = 1.429, p = 0.238 \); females left hand, \( \beta = 0.013, F = 0.008, p = 0.928 \).

### Table 1. Means (\( M \)) and standard deviations (SD) for age, weight, height, body circumferences and anthropometric indices.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Males ( (n = 30) )</th>
<th>Females ( (n = 50) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>22.47</td>
<td>22.90</td>
</tr>
<tr>
<td>Weight</td>
<td>79.20</td>
<td>60.15</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179.70</td>
<td>164.22</td>
</tr>
<tr>
<td>Chest circumference (cm)</td>
<td>95.58</td>
<td>88.53</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>80.71</td>
<td>71.87</td>
</tr>
<tr>
<td>Hip circumference (cm)</td>
<td>88.94</td>
<td>88.75</td>
</tr>
<tr>
<td>BMI</td>
<td>24.59</td>
<td>22.27</td>
</tr>
<tr>
<td>WHR</td>
<td>0.90</td>
<td>0.81</td>
</tr>
<tr>
<td>WCR</td>
<td>0.84</td>
<td>0.81</td>
</tr>
</tbody>
</table>
Weight: males, right hand, $\beta=0.159$, $F=0.722$, $p=0.403$; males left hand, $\beta=0.287$, $F=2.522$, $p=0.124$; females, right hand, $\beta=-0.102$, $F=0.501$, $p=0.483$; females left hand, $\beta=-0.103$, $F=0.518$, $p=0.475$.

Therefore we did not control for the effect of these variables when considering the relationship between body circumferences and anthropometric indices. Table 2 shows the relationship of 2D:4D right hand, and 2D:4D left hand with chest circumference, waist circumference, hip circumference, WHR, WCR and BMI for males and females.

Most of the relationships were in the predicted direction though we did not find a significant correlation between 2D:4D and WHR for both males and females, as in a previous study (see Manning 2002). Waist and hip circumferences were significantly negatively related to 2D:4D (both hands) in females whereas in males chest circumference was found to be positively correlated with left and right hand 2D:4D but remained non-significant. WCR was found to correlate significantly negatively with 2D:4D (both hands) in females but not in males (though the relationship was in the same direction, see figures 1 and 2). Finally, we found a strong positive association between BMI and 2D:4D for the left hand in males (figure 4). The same relationship was found in males’ right hands but was non-significant (figure 3). According to the predictions, in females BMI correlated negatively with 2D:4D (both hands) but this association was not significant (figures 3 and 4).

4. Discussion

The results of this study provide further evidence that the ratio between the length of the second digit and the fourth digit (2D:4D) is a sexually dimorphic trait with males having a significantly lower ratio than females. In addition, we found some evidence that 2D:4D also correlates with indices of sexually dimorphic traits of the human body. These relationships were found to be stronger for females than for males. Since 2D:4D is supposedly related to prenatal hormonal levels (Manning et al. 2002)
(1998, Manning 2002) the present data suggest an early organizational effect of sex hormones—at least for females—through the association between indices of body shape and finger length patterns.

Previous work has shown that testosterone is related negatively to 2D:4D whereas oestrogen correlates positively with 2D:4D (Manning et al. 1998). Consequently, we hypothesized that androgenized forms of the 2D:4D would correlate with androgenized forms of BMI, WHR and WCR. Basically, the present data provide some further evidence that that this supposition holds true in both sexes for the physical characteristics described in this study, though we must note that the strongest asso-

Figure 1. The relationship between right hand 2D:4D and WCR in males and females. The curves represent the regression prediction lines for a confidence interval of 95%.

Figure 2. The relationship between left hand 2D:4D and WCR in males and females. The curves represent the regression prediction lines for a confidence interval of 95%.
Associations were found between body circumferences, and WCR in females and 2D:4D. What might be concluded from the results of this study?

Body fat distribution as measured by WHR has been repeatedly shown to correlate with levels of testosterone, oestrogen, and risk for major diseases such as diabetes, hypertension, ovarian disorders and carcinomas (for review see Singh 1993). Healthy females have higher levels of oestrogen than testosterone. This causes more fat to be deposited on the buttocks and hips than on the waist, giving a low WHR (Beck et al. 1976). Consequently, WHR has been suggested to be an ‘honest’ signal to an individual’s fertility and health. Although, men and women differ in the values of their WHR as testosterone stimulates fat deposition in the...
stomach region and inhibits a build up in the buttocks and thighs, and oestrogen produces the contrasting effect, it seems that this assertion is valid for both sexes. Previous studies have shown that digit ratio underlies this relationship as lower 2D:4D (the androgenized form) correlates negatively with WHR (Manning 2002). The present study did, however, not find a significant association for male and female digit ratio with WHR. Singh (1995) pointed out that the size of adult male WHR might be indicative of adverse developmental conditions. They found that women judged normal weight male figures with WHR in the typical male range (i.e. around 0.90) more attractive and healthy. Medical studies have shown that oestrogen significantly increases with obesity in men and women (Kley et al. 1980, Kirschner et al. 1981) leading to the suggestion that fat tissue is able to aromatize androgens. The results of the present study supports this argument to some extent as BMI was related significantly positively to left hand 2D:4D in males. In females the reversed relationship was found but remained not significant. We suppose that men who express lower levels of androgens tend to have a higher BMI whereas female 2D:4D ratio follows the suggestion that oestrogens relate positively to body fat, but this hypothesis needs to be proved in future studies.

We did not find a significant relationship between WCR and 2D:4D in males, but in women WCR related significantly negatively with 2D:4D, i.e. a higher value of 2D:4D (less androgenized) correlated with a lower value of WCR. This is consistent with the literature, as oestrogens should largely influence female chest circumference. Our results on the relationship of 2D:4D in men do not support this assertion, i.e. 2D:4D was related negatively with WCR as for females. Male muscles are built under the influence of testosterone and will be of use for male–male competition. Therefore we assumed that WCR would correlate negatively with 2D:4D in males as this may indicate a muscular upper body. However, we did not find this relationship.

In summary, the results of our study are consistent to some extent with the sexual dimorphism of physical traits developed under the influence of sex hormones at puberty. Male and female body shape is influenced by sex-steroid ratios. Whereas organizational effects are supposed to modify an organism early in life—primarily influencing its anatomy—activational effects are apparent later in life and influence the way previously established structures function. If the assertion of an organizational and activational effect of hormones were true, we may suppose that evidence will accumulate that this finds its expression also in finger length patterns. The present data suggest this, but further investigation is required to obtain a more detailed picture of possible associations.

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References

Geschlechtsdimorphismus, da Männer eine geringere 2D:4D Ratio haben. Dieser Geschlechtsdimorphismus wird bereits in der 14. Fetalwoche festgelegt und ändert sich nicht bis zur Pubertät. Es gibt Belege, dass die Geschlechtsunterschiede in der 2D:4D Ratio auf den Konzentrationen der Sexualsteroiden in utero beruhen, wobei eine niedrigere 2D:4D Ratio (d. h. eine für Männer typische Ratio) in positiver Beziehung zum pränatalen Testosteron steht. Dagegen ist eine hohe 2D:4D Ratio (d. h. eine für Frauen typische Ratio) positiv mit dem pränatalen Östrogen assoziiert.


Resume. Arrière-plan: On a beaucoup discuté de l’effet possible des stéroïdes sexuels prénataux sur la différenciation du cerveau, alors que par ailleurs on pense que les hormones sexuelles pubertaires et adultes sont les principaux régulateurs du dimorphisme des traits physiques masculins et féminins. Il a été jusqu’ici difficile de rendre compte de l’exposition aux stéroïdes prénataux, mais il apparaît maintenant à l’évidence que le rapport de la longueur du doigt puisse offrir une “fenêtre” d’estimation de l’exposition prénatale à l’hormone. La longueur du 2ème doigt (l’index) par rapport à celle du 4ème doigt (l’annulaire) est sexuellement dimorphique car les garçons ont un rapport 2D:4D plus bas que les filles. Le dimorphisme sexuel est déterminé dès la 14ème semaine de vie foetale et demeure inchangé à la puberté. Il y a évidence que les différences de sexe en 2D:4D proviennent des concentrations en stéroïdes sexuels in utero, un rapport bas 2D:4D (typiquement masculin) étant positivement associé à de la testostérone prénatale, tandis qu’un rapport 2D:4D élevé (typiquement féminin) est positivement associé à l’œstrogène prénatal.

But: Observer si et dans quelle mesure, les traits physiques sexuellement dimorphiques des adultes sont associés à des traits qui sont essentiellement déterminés in utero. Ce travail examine la relation entre trois caractères dimorphiques: l’indice de masse corporelle (IMC), le rapport taille-hanches (RTH) le rapport taille-thorax (RTT) et le rapport des doigts.

Participants et méthodes: Pour obtenir l’IMC, le RTH et le RTT, on a mesuré la stature, le poids et les circonférences de la taille, du thorax et des hanches de 30 hommes et 50 femmes hétérosexuels. Les longueurs des deuxièmes et quatrièmes doigts ont été estimées à partir de photocopies de la face palmaire de la main et par des mesures directes.

Résultats: le rapport digital est significativement plus bas chez les hommes que chez les femmes. Des corrélations négatives et significatives ont été trouvées entre les 2D:4D des mains droite et gauche des femmes et la taille, la circonférence des hanches et le RTT. Chez les hommes, l’IMC est positivement associé au 2D:4D mais la corrélation n’est significative que pour la main gauche. En général, les associations sont plus fortes chez les femmes que chez les hommes. Bien que toutes les associations ne soient pas significatives, elles vont dans le sens des prédictions.

Conclusion: Ces données suggèrent qu’il existe un effet très précoce des hormones sexuelles sur l’organisation du corps, par leur association avec les indices de la forme corporelle féminine, l’IMC masculin et avec la structure digitale. Cet effet s’ajoute à celui qui est produit par leur activation lors de la puberté.

Resumen. Antecedentes: Los esteroides sexuales prenatales han sido ampliamente discutidos en referencia a su posible efecto sobre la diferenciación cerebral, en cambio se piensa que las hormonas sexuales puberales/adultas son las principales reguladoras de las características físicas sexualmente dimórficas en varones y mujeres. Medir la exposición prenatal a los esteroides era antes difícil, pero ahora las evidencias sugieren que el cociente de la longitud de los dedos proporciona una vía para evaluar dicha exposición. La longitud del 2o dedito (dedo índice) comparada con la longitud del 4o dedo (dedo anular) es sexualmente dimórfica, pues los varones poseen un menor cociente 2D:4D. El dimorfismo sexual se determina temprano, a la semana 14 de la vida fetal, y permanece invariable hasta la pubertad. Existen evidencias de que las diferencias sexuales en el cociente 2D:4D surgen a partir de las concentraciones de esteroides sexuales in utero, con un bajo 2D:4D (cociente típico masculino) positivamente relacionado con la testosterona.
prenatal, mientras que un elevado cociente 2D:4D (típico de las mujeres) está positivamente asociado con los estrógenos prenatales. **Objetivo:** Determinar si, y en qué medida, los rasgos físicos adultos sexualmente dimórficos, que se definen ampliamente en la pubertad, se relacionan con rasgos que están en gran medida determinados *intra utero*. Este trabajo examina la relación entre 3 rasgos sexualmente dimórficos, como son el índice de masa corporal (BMI), la relación cintura/cadera (WHR) y la relación cintura/pecho (WCR), y el cociente de los dedos. **Participantes y métodos:** Se estimaron el BMI, el WHR y el WCR en 30 varones y 50 mujeres heterosexuales, mediante el registro de su estatura y peso, y midiendo sus circunferencias de cintura, cadera y pecho. Las longitudes digitales de los dedos 2° y 4° se midieron a partir de fotocopias de la superficie ventral de la mano y por medidas actuales de los dedos. **Resultados:** El cociente digital era significativamente menor en los hombres que en las mujeres. Se encontraron correlaciones negativas significativas entre los cocientes 2D:4D de las manos izquierda y derecha de las mujeres, sus circunferencias de cintura y cadera, y la relación cintura/pecho. En varones, se encontró que el índice de masa corporal estaba positivamente relacionado con el cociente digital, pero sólo de forma significativa con el 2D:4D de la mano izquierda. En general, las relaciones eran mayores para las mujeres que para los hombres. Aunque no todas las relaciones fueron significativas, estaban de acuerdo con nuestras predicciones. **Conclusión:** Además de un efecto activador de las hormonas sexuales en la pubertad, los datos aquí presentados sobre la asociación entre índices de forma corporal femeninos, el BMI masculino y los patrones de longitud de los dedos humanos sugieren un temprano efecto organizador de las hormonas sexuales.