RESEARCH ARTICLE

THE RATIO OF THE 2ND TO 4TH FINGER LENGTH PREDICTS SPATIAL ABILITY IN MEN BUT NOT WOMEN

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ABSTRACT

On average men score higher on time-constrained tests of spatial ability than women. Both brain and behaviour are influenced by prenatal and adult exposure to gonadal steroid hormones. In humans the ratio of the 2nd to 4th finger length (2D:4D) is a sexually dimorphic character that is lower in men than women and negatively correlated with testosterone levels. We report three independent studies from Sweden/London, Hungary and Liverpool confirming that 2D:4D is generally larger in women than men, that men obtain higher MRT scores than women, and demonstrating that 2D:4D is negatively correlated with MRT score in men but not women. We argue that this negative correlation between 2D:4D and spatial ability reflects the association between 2D:4D and prenatal, rather than adult, exposure to testosterone and conclude that testosterone exposure influences brain development leading to better performance on male-favouring spatial tasks.

Key words: finger length, 2D:4D ratio, mental rotation, testosterone, sex differences

INTRODUCTION

It has been widely reported that men show superior performance on spatial and mathematical tasks while women excel at verbal and fine motor tasks (Halpern, 2000; Maccoby and Jacklin, 1974). In addition to socio-cultural factors, two potential biological influences on cognitive abilities have been identified. One influence is prenatal gonadal hormones, which exert long-lasting organisational influences on the development of brain and behaviour in rodents (Williams, 2002) and humans (Collaer and Hines, 1995). The second influence is fluctuating sex hormones in adulthood that exert transient activational effects on brain organisation (Sanders and Wenmoth, 1998a, 1998b) and cognitive performance (Hampson, 1990; Hampson and Kimura, 1988; Van Goozen et al., 1994, 1995). One way in which hormones may influence brain function has been proposed by Geschwind and Galaburda (1985). They suggested that prenatal testosterone delays the maturation of the left cerebral hemisphere resulting in more rapid development of the right hemisphere. If so, males, who typically experience a greater prenatal exposure to testosterone, are more likely than females to be right hemisphere dominant. Levy (1969, 1971) argued that such sex differences in functional cerebral asymmetry may explain the known sex differences in cognitive abilities.

If prenatal testosterone exposure influences neuropsychological development then we should expect predictable associations between cognitive performance and markers for prenatal testosterone. Where should we look for such prenatal markers? The existence of a genetic link between the prenatal development of the gonads, hands and feet (Herault et al., 1997; Kondo et al., 1997; Peichel et al., 1997) is consistent with the view that distal limb characteristics may reflect prenatal testosterone exposure. Thus it is notable that sex differences have been reported for four somatic distal limb characteristics. However, as we shall see, for only one of these characteristics have both its measurement and the sex difference proved to be reliable.

Of the four characteristics those of the foot appear to be less interesting than those of the hand. A sex difference in foot size asymmetry (Levy and Levy, 1978) has not been replicated while for toe length ratios (McFadden and Shubel, 2002) measurement was difficult and the size of the sex difference small. A sex difference in finger ridge asymmetry has been reported by Kimura and Carson (1995) and Sanders and Kadam (2001) but not Holt (1968) or Slabbekoorn et al. (2000). However, finger ridge asymmetry is notable because it has been associated repeatedly with performance on sexually dimorphic cognitive and motor tasks (Kimura and Carson, 1995; Sanders and Kadam, 2001; Sanders and Waters, 2001). It was these findings that encouraged us to look for a similar link with the fourth distal limb characteristic, finger length ratio, that is readily measured and for which the sex difference is reliable.

The relative length of the 2nd and 4th fingers is sexually dimorphic (Baker, 1888; Manning et al., 1998). Whereas in women these two fingers tend to be about the same length, in men the 2nd is typically shorter than the 4th finger. Thus men on average have lower 2D:4D ratios than women. This sex difference has been shown to be present in a number of European, Caribbean, African and Asian populations (Manning et al., 2000; Manning, 2002). In addition to the sex difference, there are other reasons for thinking that 2D:4D may be related to prenatal testosterone exposure. First, there is cross-sectional evidence that much of the variance of relative finger length is set before birth, probably by week 14 of pregnancy (Garn et al., 1975; Manning et al., 1998). However, these data need to be confirmed by longitudinal studies because relative length of hand bones may not be constant throughout life (Harris et al., 1992). Second, the 2D:4D of mothers is similar to that of their children and maternal 2D:4D correlates negatively with testosterone levels in the amniotic fluid of their foetuses (Manning, 2002). Third, the waist:hip ratio of mothers, which is a positive correlate of testosterone, is negatively related to the 2D:4D of their children (Manning et al., 1999). Thus mothers with the female typical small waist and larger hips tend to have children with the female typical high finger length ratio with the 2nd and 4th fingers of approximately equal length. Conversely, those mothers with the male typical small waist and hips tend to have children with the male typical low 2D:4D ratio with the 2nd finger shorter than the 4th finger. Fourth, human males and females with congenital adrenal hyperplasia (a trait associated with high prenatal levels of adrenal androgen) have lower more masculinised 2D:4D ratios than their sex-matched controls (Brown et al., 2002; Okten et al., 2002). Fifth, high androgen sensitivity (as determined by variation in the androgen receptor gene) and low 2D:4D are both associated with high sperm numbers and protection against breast cancer (Manning et al., 2002). Sixth, low numbers of glutamine-coding repeats in the androgen receptor are associated with high sensitivity to testosterone and low 2D:4D ratios (Manning et al., 2003).

Prompted by the published associations between cognitive pattern and finger ridge asymmetry we decided to look for possible relationships between finger length ratio and cognitive performance. As these were among the first studies of this kind we wished to maximise the possibility of finding an association by using a task that reliably generates large sex differences. Reviews of sexually dimorphic tasks have repeatedly concluded that the largest sex differences are generated by certain spatial tasks, especially mental rotation tasks (see for example Halpern, 2000, pp. 111-112). From among the available mental rotation tasks we chose two, the Philips S&M test (Phillips, 1979) and Vandenberg and Kuse (1978). Both tasks are based on the figures from Shepherd and Metzler (1971) and both reliably generate male-favouring sex differences with large effect sizes. Given that prenatal testosterone is thought to masculinise brain development and subsequent performance on sexually dimorphic cognitive tasks we predicted that the male-typical low 2D:4D ratio would be associated with higher performance on these male-favouring mental rotation tasks. Here we report three independent studies, conducted concurrently in Sweden and London UK (author GS), in Hungary (authors TB and AC) and in Liverpool UK (author JM), which measured 2D:4D and performance on a mental rotation task in samples of men and women.

Materials and Methods

Participants

Study 1 Sweden and London. The 24 men and 24 women (mean ages 25.92 ± 4.74 and 27.04 ± 4.67 years) were recruited from among predominantly student populations via direct personal contact and "word-of-math" recommendations. Almost all of the participants were Scandinavian by birth with half (13 men and 11 women) recruited and tested in Sweden, the others in London.

Study 2 Hungary. The 44 men and 44 women (mean ages 22.50 ± 3.00 and 22.23 ± 1.88 years) were recruited from undergraduate students via direct personal contact. All participants were white Caucasians.

Study 3 Liverpool. The 47 men and 51 women (mean ages 31.73 ± 9.83 and 30.25 ± 10.05 years) were recruited from undergraduate and postgraduate students. The participants were approached in libraries and a sports centre and recruited into the study. All participants were white Caucasians.

Procedure

The 2D:4D Finger Length Ratio

In all three studies we measured the length of the second (2D) and fourth (4D) finger of each hand with steel callipers measuring to 0.1 millimetres. The measurement was taken from the ventral surface of the hand from the tip of the digit to the basal crease proximal to the palm. The 2D:4D ratio was calculated separately for the right and left hands. In order that repeatability of the 2D:4D ratios could be calculated finger measurements were made twice during a single testing session by the same investigator for 20 hands in the *Study 1 Sweden/London*, 88 hands in the *Study 2 Hungary* and 50 hands in *Study 3 Liverpool*. The repeat measurements were not made consecutively. At least one other hand was measured between the first and second measurements of any one hand. This was done to reduce the possibility that the second measurement could be influenced by the memory of the first measurement.

TABLE I

2D:4D Finger Length Ratios (Mean and SD) for the Three Studies Plus Effect Sizes Expressed in Standard Deviation Units and the Significance of the Sex Difference

	Study 1 Sweden/London	Study 2 Hungary	Study 3 Liverpool
Men (n = 24, 44, 47)	.95 ± .05	.97 ± .02	.99 ± .04
Women (n = 24, 44, 51)	1.01 ± 0.04	.98 ± .03	.99 ± .03
Effect size, *d*, in SD units	1.11	.39	.11
Statistical significance (t-test)	.0001	.10	.61

The Mental Rotation Tasks

Study 1 Sweden/London study used the Philips S&M Mental Rotation Task (MRT) (Phillips, 1979) which requires participants to respond *same* or *different* to 20 pairs of Shepherd and Metzler figures that are either the same but rotated or mirror images that are also rotated. All the participants completed this task twice using the same version of the task, once in the morning (06.00-08.00) and once in the afternoon (16.00-20.00) in a counterbalanced repeated measures design. The second test session occurred 2 or 3 days after the first. Possible order effects from test one to test two were analysed and are considered below (see Table II and the accompanying text). Women were tested during the period from four days before up to four days after the start of menses, i.e. during the low oestrogen phase of their cycles. We chose this period because it provided a large, readily identified window for the 2 to 3 days required for the testing in order to satisfy another aim of the study: the investigation of within sex changes in cognitive performance between morning and afternoon test sessions. Although the performance of women is closer to that of men during low oestrogen phases the MRT is strongly sexually dimorphic and we reasoned that the sex difference in performance would remain albeit somewhat reduced.

Study 2 Hungary and *Study 3 Liverpool*. Both studies used the 40 item Vandenberg and Kuse (1978) version of the Shepherd and Metzler mental rotation task (maximum score 40). In this task participants are required to match to a sample two from four figures of which the matching two are merely rotated while the non-matching two are rotated mirror images. Testing was not restricted within the day nor within the menstrual cycle.

Results

2D:4D Finger Length Ratios

Repeatabilities (intra-class correlation coefficients, r_1) of the 2D:4D ratios were high in all three studies (Sweden/London r_1 = .997; Hungary r_1 = .93; Liverpool r_1 = .92). Repeated measure ANOVA analyses showed that the ratio (F) of between-individual differences in 2D:4D to measurement error was high and significant (Sweden/London F = 770.30, p = .0001; Hungary F = 27.02, p = .0001; Liverpool F = 27.79, p = .0001). We concluded that our 2D:4D ratios represented real differences between individuals. Table I shows the 2D:4D finger length ratio data from each of the three studies. In terms of effect size the sex difference was large and significant in Study 1, moderate in Study 2 and small in Study 3. Previous studies of populations from Hungary and England have reported statistically significant sex differences in 2D:4D (Manning, 2002). In this light, the failure to find significant sex differences in Studies 2 and 3 was surprising and probably the result of sampling effects.

Mental Rotation Task (MRT)

In *Study 1 Sweden/London* mental rotation performance was measured on two occasions two or three days apart using the same version of the Philips S&M Mental Rotation Task (Phillips, 1979). We subjected these data to a two-way ANOVA that revealed a significant Sex × Test interaction (F = 5.86, p = .02) produced by a small increase in male MTR scores combined with a small decrease in female MRT scores from Test 1 to Test 2. However, there was no overall effect of repeat testing (F = .16, p = .73) and a strong effect of sex on MRT performance with men scoring higher than women (F = 55.61, p = .0001). In fact, as seen in Table II, a significant sex difference favouring men was recorded for both the first and the second test as well as for the combined scores with effect sizes of .90 standard deviations or greater. A significant male advantage in MRT performance was confirmed by Studies 2 and 3 (Table III). As in Study 1 the effect sizes were large with values of 1.28 and .80 standard deviations respectively.

Correlations between MRT Scores and 2D:4D Ratios

Participants' MRT scores were correlated with their right hand, left hand and mean 2D:4D ratios. Table IV shows the product-moment correlation coefficients and associated one-tailed probabilities for males and females in each of the three studies separately and for the combined data from these studies. Figures 1 and 2 show MRT standard scores regressed on mean 2D:4D ratio for males

TABLE II

Mental rotation scores (Mean and SD) from study 1 Sweden/London plus effect sizes expressed in standard deviation (SD) units and the significance of the sex difference

	Test 1 (Max. score 20)	Test 2 (Max. score 20)	Combined (Max. score 40)
Men (n = 24)	10.5 ± 1.98	11.67 ± 1.61	22.17 ± 3.10
Women (n = 24)	8.38 ± 2.26	7.5 ± 2.34	15.88 ± 4.22
Effect size, *d*, in SD units	.90	1.44	1.3
Statistical significance (t-test)	.001	.0001	.0001

Tests 1 and 2 used the same versions of the Phillips S&M Mental Rotation Task (Phillips, 1979) administered during the morning or the afternoon two to three days apart in a counterbalanced repeated measures design.

TABLE III

Mental rotation scores (Mean and SD) from study 2 Hungary and study 3 Liverpool plus effect sizes expressed in standard deviation (SD) units and the significance of the sex difference

	Study 2 Hungary (Max. score 40)	Study 3 Liverpool (Max. score 40)
Men (n = 44 and 47)	22.25 ± 7.24	24.61 ± 8.87
Women (n = 44 and 51)	11.93 ± 5.01	16.98 ± 8.68
Effect size, *d*, in SD units	1.28	.80
Statistical significance (t-test)	.0001	.0001

Both studies used the Vandenberg and Kuse (1978) Mental Rotation Task administered once.

TABLE IV

Correlation coefficients (r) and one-tailed probabilities (p) for MRT score and 2D:4D ratio (right hand, left hand and mean of right and left hands). The data are shown for each study separately and for the three studies combined

	Study		Sweden/London		Hungary		Liverpool		Combined	
Males	2D:4D		n = 24		n = 44		n = 47		n = 115	
	Right hand	r *p*	– .16	*.23*	– .25	*.05*	– .40	*.003*	– .32	*.0003*
	Left hand	r *p*	– .39	*.03*	– .30	*.03*	– .22	*.07*	– .31	*.0005*
	Mean of right and left	r *p*	– .39	*.03*	– .32	*.02*	– .33	*.01*	– .35	*.0001*
Females	2D:4D		n = 24		n = 44		n = 51		n = 119	
	Right hand	r *p*	– .33	*.06*	– .13	*.20*	.15	*.30*	– .02	*.40*
	Left hand	r *p*	.02	*.47*	– .18	*.13*	.16	*.15*	.01	*.45*
	Mean of right and left	r *p*	– .02	*.46*	– .13	*.20*	.18	*.11*	.01	*.44*

and females respectively from each of the three studies.

For males, all of the 12 correlations between MRT and the three measures of 2D:4D were negative and 10 of the 12 were significant at p = 0.05 or beyond (Table IV). The two correlations that failed to reach significance were MRT and left hand 2D:4D in the Liverpool study (p = .07) and MRT and right hand in the London/Sweden study (p = .23). However, with the larger sample provided by the combined data we found significant correlations between MRT and each of the 2D:4D measures (right hand, left hand and mean) at p = .0005 or beyond (Table IV). In addition, it is important to note that each of the three independent studies revealed a significant negative correlation for males between MRT and mean 2D:4D at p = .03 or beyond (Table IV and Figure 1).

For females, none of the 12 correlations was significant at p = .05 (Table IV). Neither the larger sample provided by the combined data (Table IV) nor the use of mean 2D:4D in each of the three studies separately revealed a significant correlation with MRT (Table IV and Figure 2).

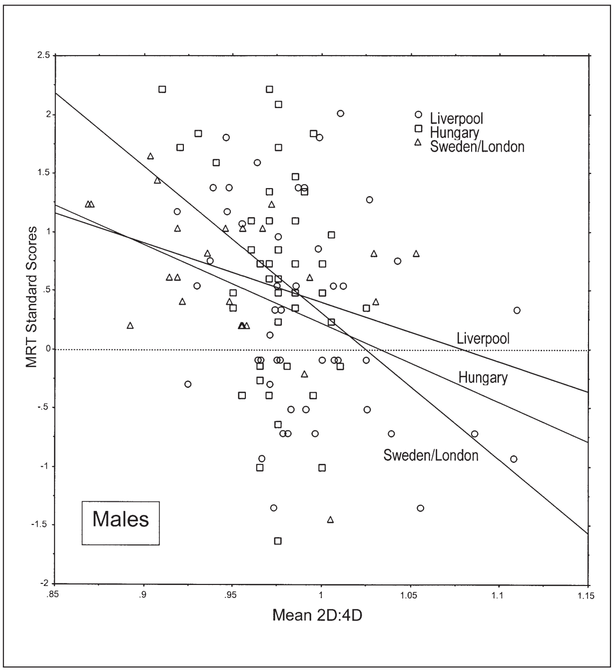

Fig. 1 – *Male scores on the mental rotation task regressed on the mean 2D:4D ratios revealed a significant negative correlation (Table IV) in each of the three independent studies.*

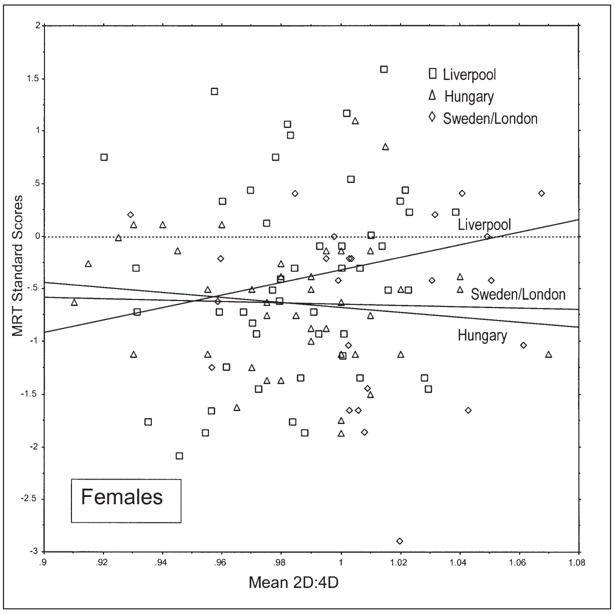

Fig. 2 – *Female scores on the mental rotation task regressed on the mean 2D:4D ratios revealed no correlation (Table IV) in any of the three independent studies.*

Discussion

For men, but not for women, there was a significant negative correlation between performance on the mental rotation task (MRT) and the 2D:4D finger length ratio. In the male data a negative correlation was found for each of the three independent studies when the mean of right and left hand ratios was used as the measure of 2D:4D (Table IV and Figure 1) and for all three measures of 2D:4D (right hand, left hand and mean) when the combined data from the three studies were used (Table IV). In fact, for men, only 2 of 12 negative correlations failed to reach significance. In the Liverpool study, the correlation between MRT and left hand 2D:4D ratio just failed to reach significance ($p = .07$). The other non-significant correlation, between MRT and right hand 2D:4D, came from the Sweden/London study which had the smallest sample sizes of the three studies (Table IV). For the female data, each of the three independent studies was in agreement as none of the 12 correlations between MRT and 2D:4D were significant (Table IV and Figure 2). As there are geographical and ethnic differences in 2D:4D (Manning et al., 2000) it is notable that the significant negative correlation between MRT score and 2D:4D was replicated in each of the independent studies conducted in Sweden/London, Hungary and Liverpool.

Our finding of a negative correlation between MRT and 2D:4D in men is consistent with reports by Manning and Taylor (2001) and McFadden and Shubel (2003). In addition, as in the present three studies, McFadden and Shubel (2003) also failed to find significant correlations for women. However, it is well documented that sex differences are frequently elusive and their appearance may be dependent on a number of factors (for a review of this issue see Sanders et al., 2002). Hence it is not surprising that there have been reports of failures to find a significant negative correlation between MRT and 2D:4D in men (Austin et al, 2002; Coolican and Peters, 2003). Thus to date 5 of 8 studies have found a negative correlation between MRT and 2D:4D in men and 4 of those studies have found this correlation in men but not women.

Gonadal steroids are known to influence brain and behaviour both before birth and in adulthood. If the negative correlation between MRT score and the 2D:4D finger length ratio in men is testosterone-related it could arise from prenatal effects, adult effects or a contribution from each. A prenatal influence might be expected because 2D:4D is thought to be fixed before birth and negatively related to foetal testosterone. Thus our finding for men would be consistent with a prenatal influence of testosterone on brain development that gives rise to sex-related differences in brain organisation and cognitive performance. The absence of a similar association in women may reflect the fact that their prenatal testosterone is typically low and consequently, they experience a substantially reduced range of exposure. An adult influence might be expected because 2D:4D ratios may correlate negatively with adult levels of testosterone (Manning et al., 1998), and higher scores on the MRT may be associated with higher adult testosterone levels. We favour a major contribution from the prenatal rather than adult effects of testosterone for several reasons.

First, support for a prenatal influence comes from the relationship that exists between asymmetric dermal ridge counts taken from fingerprints and performance on sexually dimorphic tasks. Male-favouring tasks are performed better by individuals with more ridges on the right while female-favouring tasks are performed better by those with more ridges on the left. This finding is not only seen in adults (Kimura and Carson, 1995; Sanders and Waters, 2001) but it has also been reported for children before puberty when testosterone has not surged to adult levels (Sanders and Kadam, 2001). This finding is consistent with a major contribution from prenatal rather than adult testosterone exposure.

Second, Manning et al. (1998) reported a negative association between adult male 2D:4D and testosterone, however, those data were from a sample of men attending an infertility clinic and may have been influenced by a few participants with very low testosterone. More recent samples have confirmed the negative association between adult male 2D:4D and adult testosterone among attendees at an infertility clinic but not in a general population sample (author JM, unpublished data). Furthermore, Neave et al. (2003), did not find a relationship between salivary testosterone and 2D:4D in a sample of male university students. The absence of a correlation between testosterone and 2D:4D in the general population is consistent with the view that the relationship between 2D:4D and spatial ability is mediated by prenatal rather than adult testosterone.

Third, a number of studies (Gouchie and Kimura, 1991; Kimura, 1999; Moffat and Hampson, 1996; Sanders et al., 2002; Shute et al., 1983) have indicated that the relationship between cognition and adult levels of testosterone is an inverted U-shaped function. Although the outcomes of these studies are not completely consistent, a general pattern emerges. At least for spatial tasks, women with higher adult testosterone levels outperform women with lower levels whereas for men the reverse is true. On spatial tasks, men with lower adult levels of testosterone outperform those with higher levels. If 2D:4D is negatively correlated with adult testosterone levels, why in the present studies is there no relationship in women and why is the U-shaped relationship with spatial ability not reflected in the male data? Again the absence of these effects is consistent with the view that the relationship between 2D:4D and spatial ability is mediated by prenatal rather than adult testosterone.

The findings from the three independent studies reported here indicate that the 2D:4D finger length ratio could prove a useful tool for the investigation of biological contributions to sexually dimorphic aspects of cognition and personality. As argued above, we believe that the relationship between 2D:4D and spatial ability reflects the organisational influence of prenatal testosterone on neuropsychological development rather than the phasic activational influence of adult levels of circulating testosterone on plastic aspects of brain organisation and task performance.

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