Is 2D:4D the most sexually differentiated among finger-length ratios?

Answers from a meta-analysis

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ABSTRACT

The second-to-fourth digit ratio (2D:4D) is a sexually differentiated trait of human hand anatomy which presently is frequently used in anthropological, biomedical, and psychological studies as a putative (retrospective and indirect) marker for prenatal androgen levels. Apart from the traditionally studied 2D:4D ratio, five further finger-length ratios can be constructed for the human hand (2D:3D, 2D:5D, 3D:4D, 3D:5D, 4D:5D). These have been probed by only a minority of digit ratio studies. It is not firmly established whether all of these finger-length ratios actually exhibit sex differences and whether 2D:4D indeed is the most sexually differentiated among them. To clarify these questions, a meta-analysis on studies reporting data from mixed-sex samples on all six finger-length ratios of the right and left hands in healthy normals was conducted. This study inclusion criterion was satisfied by 18 independent samples (including two unpublished), representing 4198 individuals (1989 men and 2209 women), seven countries (Australia, Austria, China, Greece, Jamaica, the UK, and the USA), different age bands (child, young adult, and adult samples), and different finger-length measurement methods (from printouts of flatbed-scanned images or photocopies of the hands or direct measurements). The meta-analytical results showed that men invariably had lower finger-length ratios than women. Although these sex differences were significant for all six finger-length ratios, effects were not strong, but rather ranged from small ($d=-0.21$, for right-hand 4D:5D) to medium ($d=-0.44$, for right-hand 2D:4D). 2D:5D was equally sexually differentiated as 2D:4D. Sex differences for finger-length ratios calculated from nonadjacent fingers (2D:4D, 2D:5D, 3D:5D) generally were somewhat more pronounced than for those calculated from adjacent fingers (2D:3D, 3D:4D, 4D:5D). Discussed are practical consequences of these findings for digit ratio research.

Key words: 2D:4D, digit ratio, finger-length ratios, sex differences, prenatal testosterone, meta-analysis

INTRODUCTION

The second-to-fourth digit ratio (2D:4D) is known to be sexually differentiated in humans¹ as well as across a broad range of non-human vertebrate species². Human males tend to have lower 2D:4D than human females. This sex effect arises from men's greater relative length of the ring finger, as compared to their index finger³.

Sex and individual differences in 2D:4D already emerge in utero at the beginning of the second trimester^{4,5} and appear to be fairly stable during postnatal life^{6,7}. There is evidence for 2D:4D being a positive correlate of genetically mediated sensitivity to testosterone⁸ and a negative correlate of the testosterone-to-estradiol ratio in the amniotic fluid⁹. Several further strands of evidence, such as observations of altered 2D:4D in androgen-related human endocrine disorders and the experimental manipulability of 2D:4D through prenatal administration of testosterone or of endocrine disruptors in animals¹⁰, have led to the hypothesis that 2D:4D might be a useful retrospective (albeit indirect) pointer to prenatal androgen action, particularly for the organizing (long-lasting and permanent) masculinization effects which are exerted by prenatal testosterone exposure on the brain, body, and behavior¹¹.

Given this hypothesis is correct, using the 2D:4D marker would permit easily implemented and thus convenient tests into the biological bases of sex-typed human traits and phenotypes, to the extent that these are partly influenced by early sex-hormone effects. Such sex-typed candidate traits encompass a broad range of domains, including disease and health, fertility, reproduction, and sexuality, cognitive and personality dimensions, and physical performance. Owing to the exciting research prospects of this prenatal-androgen-marker hypothesis, over the past decade 2D:4D studies have become quite popular in the fields of human biology/physical anthropology and the biomedical and psychological sciences, and a multitude of research papers have considered the above domains^{3,10,12,13}. The current 2D:4D research literature is comprised of more than 300

journal articles¹⁴ (including several contributions to this journal¹⁵⁻¹⁸), more than 70 retrievable unpublished academic theses, and two research monographs on the topic^{3,13}.

The vast majority of human 2D:4D studies have considered the 2D:4D ratio only, which therefore by a wide margin is the most frequently investigated among human finger-length ratios. However, from length measurements of the index, middle, ring, and little finger six finger-length ratios can be constructed for the right and left hands in humans (2D:3D, 2D:4D, 2D:5D, 3D:4D, 3D:5D, and 4D:5D). It is difficult to establish appropriate and reliable landmarks for the measurement of thumb length¹⁹ (although such a measurement protocol has recently been proposed²⁰). More importantly, there is evidence that relative thumb length is neither sexually differentiated nor reliably or meaningfully associated with other finger-length ratios²¹, so this measure is not further considered here.

As for the other six finger-length ratios (2D:3D to 4D:5D), it is evident from the available literature that only a few studies have investigated all of these^{14,22}. Specifically, it is not firmly established whether all of these six finger-length ratios actually show sex differences. Also, it is not firmly established whether the classic and traditionally studied 2D:4D indeed shows the strongest sex effect among finger-length ratios. The scientific record on these important questions for digit ratio research is unsettled. As for examples for respective statements from the literature, based on the evidence from one study²³ it has been noted that sex differences are particularly marked for 2D:3D, 2D:4D, and 2D:5D, whereas another study¹⁸ concluded that for the left hand 2D:3D and for the right hand 2D:5D might be more strongly sexually differentiated than 2D:4D is for the respective hand, and thus these other finger-length ratios could hold more promise as retrospective biomarkers for prenatal androgen action than 2D:4D.

One recent multisample study²⁴ on this research question found that sex differences for finger-length ratios calculated from nonadjacent fingers (i.e., 2D:4D, 2D:5D,

and 3D:5D) were generally larger than those for finger-length ratios calculated from adjacent fingers (i.e., 2D:3D, 3D:4D, and 4D:5D). Specifically, in this multisample investigation the traditionally used 2D:4D ratio never yielded the largest sex effect, the 2D:5D ratio seemed to be the most and the 2D:3D ratio to be the least sexually differentiated finger-length ratio. One important limitation of the multisample study was that the findings were not based on a formal statistical aggregation of the effect sizes for the sex differences in the finger-length ratios across the samples investigated. Rather, for each sample the magnitude of the sex effect observed for the finger-length ratios was ranked and these rankings in turn were averaged across samples, thereby yielding average ranks for the magnitude of the sex effect observed for the finger-length ratios. Another limitation was that the study did not incorporate in the analysis the further published data on sex differences in all six possible finger-length ratios.

Nowadays, the principal tool for making sound conclusions about the cumulative empirical knowledge in all kinds of science is meta-analysis²⁵. Up to now, this superior approach has rarely been utilized for clarifying pending research questions in digit ratio research^{26,27}. The questions of whether the preponderantly used 2D:4D ratio shows the largest sex effect among finger-length ratios and whether all finger-length ratios show a sex effect are unsettled. Therefore, the goal of the present research was to address these questions through a meta-analysis of the available data informative for these questions.

MATERIALS and METHODS

Literature search

A recently completed first-time bibliography of all published digit ratio research¹⁴ was used to determine eligible studies for the meta-analysis. This bibliography of digit ratio research lists more than 300 publications in this field and is based on comprehensive strategies of literature search (conducted up to spring 2009). Utilized were, without language restrictions, the data bases PubMed, PsycInfo, Google Scholar, Scopus, and ISI

Web of Knowledge. Cited reference searches for the two most-cited accounts of digit ratio research^{1,3} were additionally conducted in the latter data base, as well as the reference lists of retrieved studies searched for possibly citing further studies.

Study inclusion criteria

All studies listed in the bibliography of digit ratio research were inspected. Any study reporting data from mixed-sex samples on all six finger-length ratios of the right and left hands in normal healthy humans was eligible for inclusion in the meta-analysis.

Digit ratio studies which reported not only the classic 2D:4D ratio, but nevertheless did not meet the above inclusion criteria were as follows: two studies^{6,28} considered 2D:4D as well as 3D:4D. Three studies²⁹⁻³¹ apparently measured the digits 2 to 5, but reported only on three of the six possible digit ratios (2D:4D, 2D:5D, and 3D:4D). Another study³² also measured the digits 2 to 5, but digit length relative to height, instead of the digit ratios, was calculated. Five further studies³³⁻³⁷ likewise measured the digits 2 to 5, but reported only on 2D:4D. One study³⁸ reported all six possible finger-length ratios, but used a different protocol (the Visnapuu-Jürimäe method), in that finger length was measured from the wrist joint (i.e., the distal crease of the wrist) to the tip of the fingers. One study³⁹, also using a different measurement protocol, investigated a proxy of 4D:5D, namely the relative apparent (not actual) length of the little finger.

One of the included studies²² additionally collected data on all ten possible toe-length ratios, and another study⁴⁰ measured all possible metacarpal and metatarsal length ratios (ten each) from skeletons. Two medical case-control studies ascertained all six finger-length ratios, but only for an all-male⁴¹ or an all-female⁴² control sample. These latter three studies⁴⁰⁻⁴² were therefore not included in the meta-analysis.

Study details

Based on the above inclusion criteria, the literature search yielded ten eligible studies^{7,18,22-24,43-47}, totalling 16 independent samples. The details of these studies, ordered

chronologically, are presented in Table 1. One study²⁴ was a multisample investigation, providing data on six independent samples from Austria, and one study from China⁴⁵ reported data for two ethnic groups (the Han and the Hui) separately. To this literature corpus, two unpublished data sets from the present writer's lab could be added (denoted as Samples A and B in Table 1). Sample A were 69 men and 119 women (ages: 15-90 years, $M=39$, $SD=17$) and Sample B were 90 men and 90 women (ages: 15-68 years, $M=30.3$, $SD=12.5$), all of them self-reported heterosexual, native Austrians, who volunteered to participate in research projects with a larger scope. With these two further samples, the meta-analysis was based on a total of 18 samples, representing 4198 individuals (1989 men and 2209 women). The data came from seven countries (Australia, Austria, China, Greece, Jamaica, the UK, and the USA), represented different age bands (five children, three young adult, and ten adult samples), and were based on different measurement methods for ascertaining the digit ratios (in ten samples, finger lengths were measured from printouts of flatbed-scanned images of the hands; in three samples, from photocopies; and in five samples measurements were taken directly from the fingers).

Data extraction

The Cohen d measure was used as the effect size for the meta-analysis. For each digit ratio in each sample, Cohen d was calculated as the male mean minus the female mean, divided through the square root of the weighted mean of the group variances, using the ES version 1.0 software⁴⁸. Thereby, d values lower than zero reflected lower finger-length ratios in men as compared to women.

Were the effect sizes explicitly reported in the primary studies, these were not taken at face value, but rather rechecked and recalculated; were they not reported, they were calculated from descriptive statistics provided in the primary studies. One of the studies included⁴⁴ apparently miscalculated Cohen d , according to the above formula (see these authors' Table 4). The corrected values were used in the meta-analysis. Similarly, a

further study included⁴⁶ also miscalculated Cohen d, and there are some obvious typos regarding the effect sizes reported in that paper (see these authors' Table 2). All of this was corrected, by recalculating the d values, using the subsample sizes for boys and girls and the value of the respective t statistic. From this latter study⁴⁶, only the results from the control group combined with a patient group affected by attention-deficit/hyperactivity disorder (ADHD) could be used. However, this seemed acceptable, as sex and group membership were not associated in this study. For another case-control study included⁴³, it was possible to specifically include only the control sample.

One study included in the meta-analysis⁴⁷ reported data for twin individuals. Of these, two-thirds were in the age range of 10-16 years, whereas the remainder of the sample was 17 years or older. This study was therefore classified under the child samples. Further, for this study the reported minimum sample sizes for the digit ratios (284 boys and 388 girls) were taken for the meta-analysis, as these did not much differ from the initial, total sample sizes (306 boys and 397 girls). One further study included⁷ reported data from Jamaican children aged 7-13 years, who were measured in 1998 and then again in 2002, when they were four years older. The data from the first measurement (of 1998) were taken for the meta-analysis, whilst the 2002 measurements were not considered.

Data synthesis

For each finger-length ratio, a fixed-effect model of meta-analysis^{25,49}, with Cohen d as the effect size, was calculated, for which the Comprehensive Meta-Analysis version 2.2 software was used⁵⁰. Effect heterogeneity across studies was assessed with the Cochran Q test, which is an inferential statistical test for heterogeneity, and the I^2 index, which is an effect-size measure for heterogeneity (the percentage of the observed effect heterogeneity not due to chance, i.e., sampling error; this percentage quantifies the true effect heterogeneity between studies)⁴⁹.

RESULTS

The meta-analytical results are displayed in Table 1. Overall, across studies the vast majority of d values for individual digit ratios was lower than zero, thereby indicating that men on average had lower digit ratios than women. This was not only true for the most widely investigated 2D:4D ratio, but also for the remaining five digit ratios.

The combined d values across the studies showed that there were significant sex differences on all digit ratios of the right as well as of the left hand (all $p < 0.001$ for the combined d values). The lowest sex effect emerged for right-hand 4D:5D ($d = -0.21$, which is a small effect) and the largest one for right-hand 2D:4D ($d = -0.44$, which equals a medium-sized effect). For the right hand, 2D:5D was next to equally sexually differentiated as 2D:4D ($d = -0.43$ vs. -0.44), whereas for the left hand, 2D:5D was slightly more sexually differentiated than 2D:4D, although this difference likewise was negligible ($d = -0.40$ vs. -0.38). This general lack of noticeably differentiated sex effects among the digit ratios considered was also indicated through the 95% confidence intervals calculated for the combined d values, which for the most part overlapped substantially, despite the massive total sample size of more than 4000 individuals from 18 samples, as aggregated in the meta-analysis, and the correspondingly high statistical power this analysis had.

All finger-length ratios of the right hand, except 4D:5D, showed slightly stronger sex effects than corresponding finger-length ratios of the left hand, but these right-left differences in the sex effect were also negligible, ranging from 0.01 to 0.06 for the absolute differences in the combined d values.

Tests for effect heterogeneity of sex differences in digit ratios across studies, as assessed with the Cochran Q test statistic, were nominally significant ($p < 0.05$ or lower) in eight out of 12 cases (except for left-hand 2D:4D and 4D:5D and for right-hand 2D:3D and 4D:5D). However, as indexed by the I^2 measure, which ranged from 27% (for left-hand 2D:4D) to about 65% (for right-hand 3D:4D), there was no instance of truly strong effect

heterogeneity across studies (as would be indicated by $I^2 > 75\%$, which in turn would warrant further investigation attempting to explain the observed effect heterogeneity)⁴⁹.

DISCUSSION

This study is one of the very first applications of modern meta-analysis to answer open research questions in digit ratio research^{27,28}. The vast majority of digit ratio studies have investigated only the classic 2D:4D ratio. A minority of studies have investigated additional finger-length ratios or all six possible finger-length ratios that can be constructed for the human hand. Separate inspection of these individual studies does not allow to determine upon two important and related questions for digit ratio research – only a meta-analysis does so: First, is the traditionally studied 2D:4D ratio indeed the most sexually differentiated among the human finger-length ratios? And second, do all six finger-length ratios actually exhibit a sex effect?

Statistical pooling through meta-analytical methods of the results of the primary studies that are informative for these research questions yielded quite unambiguous answers to these questions. Men on average have lower finger-length ratios than women. This is not only true for the 2D:4D ratio, but rather is invariably found for all finger-length ratios. With the statistical power given through the primary studies combined in the meta-analysis, this sex effect was nominally significant for all finger-length ratios. However, at the same time it was also obvious that sex differences in digit ratios were not large. They ranged from slightly beyond 0.2 SD units to slightly below 0.5 SD units. In other words, the sex differences in digit ratios represent small to medium-sized effects. However, sex differences in prenatal androgen levels are markedly large. From this it follows that digit ratios can only be crude and imperfect pointers to prenatal androgen levels.

As for the right hand, 2D:4D turned out to be the most sexually differentiated among the finger-length ratios, followed by the 2D:5D ratio. As for the left hand, 2D:5D was the most sexually differentiated ratio, followed by 2D:4D. However, the differences in

the respective sex effect observed for the 2D:4D and the 2D:5D ratio were next to negligible, so that it seems fair to say that sex differences of both 2D:4D and 2D:5D are of commensurable size. More generally, one key finding of a prior related study²⁵ was corroborated through the meta-analysis, in that finger-length ratios calculated from nonadjacent fingers (i.e., 2D:4D, 2D:5D, and 3D:5D) generally were somewhat more sexually differentiated than finger-length ratios calculated from adjacent fingers (i.e., 2D:3D, 3D:4D, and 4D:5D).

From these insights, several points of practical relevance for digit ratio research may be derived: first, it was reassuring to see that no other finger-length ratio was significantly or substantially more sexually differentiated than the usually studied 2D:4D ratio. Past digit ratio research has thus focused on the proper finger-length ratio. For this reason, it seems justified that digit ratio studies continue to utilize only the 2D:4D ratio. Second, it may well be redundant to consider all six finger-length ratios in digit ratio studies. Although all of these measures show a sex difference, the size of this effect is, without exception, small to medium. Hence it may well be that these measures convey very similar information and are thus to the greatest extent interchangeable. And third, if other finger-length ratios than the classic 2D:4D ratio are considered in digit ratio studies, preferentially those calculated from nonadjacent fingers (2D:5D and 3D:5D) should be included, because they exhibit somewhat stronger sex effects than those calculated from adjacent fingers.

The strength of the current investigation lies in the fact that the findings are based on a quite large sample size, totalling more than 4000 male and female subjects from 18 independent samples. The data came from seven countries located on four continents and included different age bands (child, young adult, and adult samples) and quite different methods for the ascertainment of finger-length ratios (finger lengths measured from printouts of scanned images or from photocopies of the hands or measured directly).

Given these differences in the provenience and age characteristics of the subjects and also in measurement methodology, the convergence of findings across studies is quite interesting (cf. the results of the individual studies, as assembled in Table 1). Statistical tests for cross-study heterogeneity of the sex effect seen on the finger-length ratios were, for the most part, nominally significant. This is known to be an ubiquitous feature of real-world applications of meta-analysis⁴⁹. However, in further analysis, when this effect heterogeneity was expressed as a standardized effect-size metric (I^2) and consensus benchmarks for its evaluation applied, this suggested that heterogeneity of the sex effect across studies was not strong (all $I^2 < 65\%$). Random-effects models of meta-analysis, which explicitly account for effect heterogeneity across studies⁴⁹, were additionally calculated. Results for the combined d values from these models remained essentially unchanged (details omitted), as compared with those displayed in Table 1.

For these combined reasons, subgroup analysis or meta-regression (with regard to the study-level variables geographic provenance, age band, and measurement methodology) were not undertaken. It is emphasized here that the statistical power of meta-analytical subgroup analysis with several categorical moderator variables is quite low when there are not numerous primary studies (the current meta-analysis combined 18 primary studies). In a similar vein, there is a real threat of overfitting in meta-regression models with few primary studies and several categorical moderator variables⁴⁹. Consequently, the results of meta-analytical subgroup analysis or meta-regression, when based on relatively few data points (i.e., primary studies) may well be spurious and thus unreplicable. The power of statistical tests for assessing possible publication bias in meta-analysis is also poor with a limited set of primary studies⁴⁹. For this general reason, and also because there was no real specific reason to suspect that the published literature reporting sex differences on all six possible finger-length ratios could be subject to publication bias with regards to the outcome, no such tests were conducted. Sensitivity

analysis, i.e., removal of one study at a time from the meta-analytical model⁴⁹, showed (details omitted) that for all effects assessed (Table 1) there was not a single study with an unduly influence on the respective effect found overall.

To conclude, this meta-analysis of 18 independent samples (including two unpublished samples), reporting on sex differences in the six finger-length ratios of the human hand, clarified that all of these are sexually differentiated, with these effects ranging from small to medium size, and that no other finger-length ratio is significantly more strongly sexually differentiated than the traditionally investigated 2D:4D ratio.

REFERENCES

- [1] Manning JT, Scutt D, Wilson J, Lewis-Jones DI. The ratio of 2nd to 4th digit length: a predictor of sperm numbers and concentrations of testosterone, luteinizing hormone and oestrogen. *Hum Reprod* 1998;13:3000-4.
- [2] Voracek M. Of mice and men--cross-species digit ratio (2D:4D) research: comment on Bailey, Wahlsten, and Hurd (2005). *Genes Brain Behav* 2006;5:299-300.
- [3] Manning JT. Digit ratio: a pointer to fertility, behavior, and health. New Brunswick, NJ: Rutgers University Press; 2002.
- [4] Malas MA, Dogan S, Evcil EH, Desdicioglu K. Fetal development of the hand, digits and digit ratio (2D:4D). *Early Hum Dev* 2006;82:469-75.
- [5] Galis F, Ten Broek CMA, Van Dongen S, Wijnaendts LCD. Sexual dimorphism in the prenatal digit ratio (2D:4D). *Arch Sex Behav*, in press. doi: 10.1007/s10508-009-9485-7
- [6] McIntyre MH, Ellison PT, Lieberman DE, Demerath E, Towne B. The development of sex differences in digital formula from infancy in the Fels Longitudinal Study. *Proc Biol Sci* 2005;272:1473-9.
- [7] Trivers R, Manning JT, Jacobson A. A longitudinal study of digit ratio (2D:4D) and other finger ratios in Jamaican children. *Horm Behav* 2006;49:150-6.
- [8] Manning JT, Bundred PE, Newton DJ, Flanagan BF. The second to fourth digit ratio and variation in the androgen receptor gene. *Evol Hum Behav* 2003;24:399-405.
- [9] Lutchmaya S, Baron-Cohen S, Raggatt P, Knickmeyer R, Manning JT. 2nd to 4th digit ratios, fetal testosterone and estradiol. *Early Hum Dev* 2004;77:23-8.
- [10] McIntyre MH. The use of digit ratios as markers for perinatal androgen action. *Reprod Biol Endocrinol* 2006;4:10.
- [11] Collaer ML, Hines M. Human behavioral sex differences: a role for gonadal hormones during early development? *Psychol Bull* 1995;118:55-107.

- [12] Cohen-Bendahan CCC, van de Beek C, Berenbaum SA. Prenatal sex hormone effects on child and adult sex-typed behavior: methods and findings. *Neurosci Biobehav Rev* 2005;29:353-84.
- [13] Manning JT. The finger book: sex, behaviour and disease revealed in the fingers. London: Faber & Faber; 2008.
- [14] Voracek M, Loibl LM. Scientometric analysis and bibliography of digit ratio (2D:4D) research, 1998-2008. *Psychol Rep*, in press.
- [15] Schäfer, K., Fink, B., Mitteröcker, P., Neave, N., & Bookstein, F. L. (2005). Visualizing facial shape regression upon 2nd to 4th digit ratio and testosterone. *Collegium Antropologicum*, 29, 415-419.
- [16] Buffa, S., Marini, E., Cabras, S., Scalas, G., & Floris, G. (2007). Patterns of hand variation: new data on a Sardinian sample. *Collegium Antropologicum*, 31, 325-330.
- [17] Voracek, M., Bagdonas, A., & Dressler, S. G. (2007). Digit ratio (2D:4D) in Lithuania once and now: Testing for sex differences, relations with eye and hair color, and a possible secular change. *Collegium Antropologicum*, 31, 863-868.
- [18] Kyriakidis, I., & Papaioannidou, P. (2008). Epidemiologic study of the sexually dimorphic second to fourth digit ratio (2D:4D) and other finger ratios in Greek population. *Collegium Antropologicum*, 32, 1093-1098.
- [19] Voracek, M. (2006). Sex and side differences in relative thumb length [letter]. *Journal of Hand Surgery (American Volume)*, 31, 326-327.
- [20] Voracek, M., & Offenmüller, D. (2007). Digit ratios (2D:4D and other) and relative thumb length: A test of developmental stability. *Perceptual and Motor Skills*, 105, 143-152.
- [21] GOLDFARB, C. A., GEE, A. O., HEINZE, L. K., & MANSKE, P. R. (2005) Normative values for thumb length, girth, and width in the pediatric population. *Journal of Hand Surgery (American Volume)*, 30, 1004-1008.

- [22] McFadden D, Shubel E. Relative lengths of fingers and toes in human males and females. *Horm Behav* 2002;42:492-500.
- [23] Manning, J. T., Callow, M., & Bundred, P. E. (2003). Finger and toe ratios in humans and mice: Implications for the aetiology of diseases influenced by *HOX* genes. *Medical Hypotheses*, 60, 340-343.
- [24] Voracek, M. (2009). Comparative study of digit ratios (2D:4D and other) and novel measures of relative finger length: Testing magnitude and consistency of sex differences across samples. *Perceptual and Motor Skills*, 108, 83-93.
- [25] Cooper, H. M., Hedges, L. V., & Valentine, J. C. (Eds.). (2009). *The handbook of research synthesis and meta-analysis*. New York: Russell Sage.
- [26] Hönekopp, J., Bartholdt, L., Beier, L., & Liebert, A. (2007). Second to fourth digit length ratio (2D:4D) and adult sex hormone levels: New data and a meta-analytic review. *Psychoneuroendocrinology*, 32, 313-321.
- [27] Puts, D. A., McDaniel, M. A., Jordan, C. L., & Breedlove, S. M. (2008). Spatial ability and prenatal androgens: Meta-analyses of congenital adrenal hyperplasia and digit ratio (2D:4D) studies. *Archives of Sexual Behavior*, 37, 100-111.
- [28] McIntyre, M. H., Cohn, B. A., & Ellison, P. T. (2006). Sex dimorphism in digital formulae of children. *American Journal of Physical Anthropology*, 129, 143-150.
- [29] Burton, L. A., Henninger, D., & Hafetz, J. (2005). Gender differences in relations of mental rotation, verbal fluency, and SAT scores to finger length ratios as hormonal indexes. *Developmental Neuropsychology*, 28, 493-505.
- [30] Burton, L. A., Henninger, D., Hafetz, J., & Cofer, J. (2009). Aggression, gender-typical childhood play, and a prenatal hormonal index. *Social Behavior and Personality*, 37, 105-115.
- [31] Martel, M. M. (in press, 2009). Conscientiousness as a mediator of the association between masculinized finger-length ratios and attention-deficit/hyperactivity

disorder (ADHD). *Journal of Child Psychology and Psychiatry*.

- [32] Martin, S. M., Manning, J. T., & Dowrick, C. F. (1999). Fluctuating asymmetry, relative digit length and depression in men. *Evolution and Human Behavior*, 20, 203-214.
- [33] Manning, J. T., Fink, B., Neave, N., & Caswell, N. (2005). Photocopies yield lower digit ratios (2D:4D) than direct finger measurements. *Archives of Sexual Behavior*, 34, 329-333.
- [34] Manning, J. T., Fink, B., Neave, N., & Szwed, A. (2006). The second to fourth digit ratio and asymmetry. *Annals of Human Biology*, 33, 480-492.
- [35] Rahman, Q. (2005a). Fluctuating asymmetry, second to fourth finger length ratios and human sexual orientation. *Psychoneuroendocrinology*, 30, 382-391.
- [36] Rahman, Q., & Symeonides, D. J. (2008). Neurodevelopmental correlates of paraphilic sexual interests in men. *Archives of Sexual Behavior*, 37, 166-172.
- [37] Van Dongen, S. (2009). A critical re-evaluation of the association between 2D:4D ratios and fluctuating asymmetry in humans. *Annals of Human Biology*, 36, 186-198.
- [38] Jürimäe, T., Voracek, M., Jürimäe, J., Lätt, E., Haljaste, K., Saar, M., & Purge, P. (2008). Relationships between finger-length ratios, ghrelin, leptin, IGF axis, and sex steroids in young male and female swimmers. *European Journal of Applied Physiology*, 104, 523-529.
- [39] Ghosh, D., & Garth, D. (2005). A study of finger length relation (ring finger & little finger i.e. 4D5D) with human personality. *Psychiatry Online*
[<http://www.priory.com/psych/FP23.pdf>].
- [40] McFadden, D., & Bracht, M. S. (2009). Sex and race differences in the relative lengths of metacarpals and metatarsals in human skeletons. *Early Human Development*, 85, 117-124.
- [41] Lu, H., Huo, Z.-H., Zhang, K.-J., Wei, N., Shi, Z.-Y., Peng, L., Dang, J., & Jiao, H.-Y. (2008). [Relationship between digit ratio and coronary heart disease]. *Acta Anatomica Sinica*

[Jie Pou Hsueh Bao], 39, 765-768.

- [42] Lu, H., Hou, Z.-H., Chen, J., Gao, P., Li, T., Shi, Z.-Y., Peng, L., & Dang, J. (2008). [A study of the relationship between digit ratio and breast cancer]. *Acta Anthropologica Sinica*, 27, 359-363.
- [43] McFadden, D., Westhafer, J. G., Pasanen, E. G., Carlson, C. L., & Tucker, D. M. (2005). Physiological evidence of hypermasculinization in boys with the inattentive type of attention-deficit/hyperactivity disorder (ADHD). *Clinical Neuroscience Research*, 5, 233-245.
- [44] Stevenson, J. C., Everson, P. M., Williams, D. C., Hippskind, G., Grimes, M., & Mahoney, E. R. (2007). Attention deficit/hyperactivity disorder (ADHD) symptoms and digit ratios in a college sample. *American Journal of Human Biology*, 19, 41-50.
- [45] Lu, H., Huo, Z.-H., Shi, Z.-Y., Peng, L., Dang, J., Jiao, H.-Y., Zhong, H.-J., & Cheng, Y.-T. (2008). [Study on the digit ratio of Hui and Han in ethnic groups in Ningxia]. *Acta Anatomica Sinica [Jie Pou Hsueh Bao]*, 39, 267-271.
- [46] Martel, M. M., Gobrogge, K. L., Breedlove, S. M., & Nigg, J. T. (2008). Masculinized finger-length ratios of boys, but not girls, are associated with attention-deficit/hyperactivity disorder. *Behavioral Neuroscience*, 122, 273-281.
- [47] Loehlin, J. C., Medland, S. E., & Martin, N. G. (2009). Relative finger lengths, sex differences, and psychological traits. *Archives of Sexual Behavior*, 38, 298-305.
- [48] Shadish, W. R., Robinson, L., & Lu, C. (1999). *ES: A computer program for effect size calculation*. University of Memphis.
- [49] Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2009). *Introduction to meta-analysis*. New York: Wiley.
- [50] Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2005). *Comprehensive Meta-Analysis, Version 2* [computer software]. Englewood, NJ: Biostat.

TABLE 1

META-ANALYSIS (FIXED-EFFECT MODEL) OF SEX DIFFERENCES IN ALL SIX POSSIBLE FINGER-LENGTH RATIOS

Study [ref #]	Country	N (m/f)	Ms	Age	Left hand						Right hand					
					2D:3D	2D:4D	2D:5D	3D:4D	3D:5D	4D:5D	2D:3D	2D:4D	2D:5D	3D:4D	3D:5D	4D:5D
McFadden (2002) [22]	USA	60/62	Scn	Ad	-0.49	-0.74	-0.68	-0.54	-0.39	-0.13	-0.50	-0.85	-0.76	-0.72	-0.51	-0.13
Manning (2003) [23]	UK	340/340	Dir	Ad	-0.27	-0.31	-0.30	-0.02	-0.13	-0.11	-0.15	-0.26	-0.34	-0.15	-0.14	-0.16
McFadden (2005), controls [43]	USA	17/16	Scn	Chil	-0.49	-0.83	-0.78	-0.44	-0.30	-0.36	-0.22	-0.49	-0.52	-0.37	-0.32	-0.14
Trivers (2006), 1998 measurements [7]	Jamaica	54/54	Phot	Chil	-0.90	-0.39	-0.56	-0.35	0.07	0.21	-0.04	-0.38	-0.30	-0.51	-0.32	-0.06
Stevenson (2007) [44]	USA	52/135	Dir	Ad	-0.45	-0.40	-0.15	-0.06	0.07	0.13	-0.22	-0.51	-0.09	-0.43	0.03	0.25
Kyriakidis (2008) [18]	Greece	60/60	Dir	Yng	-0.67	-0.63	-0.62	-0.16	-0.16	-0.09	-0.61	-0.75	-0.89	-0.36	-0.57	-0.35
Lu (2008), Han ethnicity [45]	China	241/219	Dir	Ad	-0.28	-0.26	-0.26	-0.19	-0.33	-0.41	-0.21	-0.28	-0.26	-0.01	-0.29	-0.21
Lu (2008), Hui ethnicity [45]	China	193/198	Dir	Ad	-0.08	-0.27	-0.05	-0.04	-0.15	-0.29	-0.11	-0.29	-0.07	0.00	-0.33	-0.29
Martel (2008), controls and ADHD [46]	USA	149/101	Phot	Chil	0.08	-0.19	-0.42	-0.17	-0.22	-0.30	-0.32	-0.51	-0.43	-0.47	-0.33	-0.20
Loehlin (2009) [47]	Australia	284/388	Phot	Chil	-0.32	-0.36	-0.39	-0.14	-0.22	-0.17	-0.42	-0.58	-0.50	-0.33	-0.27	-0.13
Voracek (2009), Sample I [24]	Austria	67/90	Scn	Ad	-0.12	-0.67	-0.79	-0.76	-0.85	-0.41	0.11	-0.49	-0.76	-0.81	-0.99	-0.49
Voracek (2009), Sample II [24]	Austria	75/75	Scn	Ad	-0.10	-0.38	-0.67	-0.42	-0.62	-0.54	0.04	-0.40	-0.57	-0.56	-0.63	-0.40
Voracek (2009), Sample III [24]	Austria	59/69	Scn	Ad	-0.21	-0.72	-0.61	-0.76	-0.48	-0.10	-0.49	-0.56	-0.58	-0.32	-0.33	-0.16
Voracek (2009), Sample IV [24]	Austria	60/64	Scn	Yng	-0.10	-0.48	-0.64	-0.51	-0.59	-0.39	-0.29	-0.52	-0.66	-0.46	-0.55	-0.40

Study [ref #]	Country	N (m/f)	Ms	Age	Left hand						Right hand					
					2D:3D	2D:4D	2D:5D	3D:4D	3D:5D	4D:5D	2D:3D	2D:4D	2D:5D	3D:4D	3D:5D	4D:5D
Voracek (2009), Sample V [24]	Austria	60/64	Scn	Yng	-0.04	-0.41	-0.47	-0.44	-0.38	-0.18	-0.17	-0.47	-0.65	-0.44	-0.48	-0.32
Voracek (2009), Sample VI [24]	Austria	60/58	Scn	Chil	-0.22	-0.30	-0.63	-0.20	-0.51	-0.47	-0.38	-0.40	-0.81	-0.16	-0.63	-0.73
Voracek (unpubl.), Sample A	Austria	69/119	Scn	Ad	0.30	-0.22	-0.34	-0.54	-0.51	-0.23	-0.17	-0.31	-0.34	-0.22	-0.24	-0.12
Voracek (unpubl.), Sample B	Austria	90/90	Scn	Ad	-0.26	-0.60	-0.71	-0.48	-0.54	-0.37	-0.29	-0.77	-0.64	-0.59	-0.50	-0.24
Combined d					-0.23***	-0.38***	-0.40***	-0.24***	-0.29***	-0.23***	-0.24***	-0.44***	-0.43***	-0.29***	-0.34***	-0.21***
LL					-0.29	-0.44	-0.46	-0.30	-0.35	-0.29	-0.30	-0.50	-0.49	-0.36	-0.40	-0.27
UL					-0.17	-0.32	-0.34	-0.18	-0.23	-0.17	-0.18	-0.38	-0.37	-0.23	-0.28	-0.15
Q (with df=17)					45.7***	23.3	40.7**	47.8***	41.8**	27.0	26.5	28.0*	46.4***	48.8***	38.8**	25.1
I ² (%)					62.8	27.0	58.2	64.5	59.4	37.1	35.9	39.2	63.4	65.2	56.1	32.2

Ms – finger-length measurement method (Scn – from scanned images, Phot – from photocopies, Dir – directly), Age – age band of the sample (Chil – children, Yng – young adults, Ad – adults), LL, UL – lower and upper

95% confidence limit of combined d, *p<0.05, **p<0.01, ***p<0.001 (for combined d and for Q test)