

DIGIT RATIOS, FINGER LENGTH, AND BASIC MUSICAL ABILITIES

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Among elite orchestra musicians (predominantly men), a lower (masculinised) second-to-fourth digit ratio (2D:4D), a putative marker of prenatal testosterone levels, has been shown to be associated with higher musical-ability rankings (Sluming & Manning, 2000). Seeking to extend this evidence, this study examined associations of digit ratios (2D:4D and other) and absolute finger length (a putative marker of pubertal-adolescent testosterone levels) with basic musical abilities (Seashore battery) in a sample of 124 adult non-musicians. Among women better pitch discrimination corresponded to lower (masculinised) digit ratios and longer (masculinised) fingers, whilst among men directionally opposite and thus not theory compliant correlations of rhythm and time discrimination with finger-length measures emerged. Similarly, although men exceeded women on most of the Seashore tasks, these sex differences were negligible, with the exception of timbre discrimination. On the whole, significant associations between the study variables were sparse and yielded little support for the assumption that prenatal or pubertal-adolescent androgen effects may partly influence within-sex individual variation in basic musical abilities among adult non-musicians.

Introduction

Are interindividual differences in musical ability possibly partly due to developmentally early, long-lasting effects of sex hormones on the human brain? To address this question, this study used simple anthropometric measures of the human hand that have become quite popular in recent research as putative biomarkers for early sex-hormone action.

The relative length of the index finger (second digit or 2D) to the ring finger (fourth digit or 4D), i.e., the second-to-fourth digit ratio (hereafter 2D:4D), is sexually differentiated in humans as well as across a wide range of non-human species, such as other primates, rodents, avian, lizard, and amphibian species (e.g., Chang, 2008; Lombardo & Thorpe, 2008; partial review: Voracek, 2006). In humans, men on average show a lower 2D:4D than women. That is, compared to women, men's 4D is longer relative to

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their 2D. In many samples, the size of this sex effect is about one-half standard deviation unit (Manning, 2002). This is an inconspicuous detail of human hand anatomy, but it was already noted by anatomists, physical anthropologists, and forensic physicians of the late 19th century (Baker, 1888; Ecker, 1875; Grüning, 1886; Mantegazza, 1877). Although there has been occasional research on the 2D:4D ratio across most of the 20th century (partially reviewed in Peters, Mackenzie, & Bryden, 2002), publications were not numerous and the topic remained a peripheral one for most of the time. In hindsight, this seems to have been mainly due to the fact that there was no theory to account for the sex difference seen in 2D:4D, which turned out to be a reliable and robust effect that is highly replicable across samples, study locales, and measurement methods.

These matters of fact changed fundamentally in the late 1990s with an influential paper (Manning, Scutt, Wilson, & Lewis-Jones, 1998) that triggered modern 2D:4D research. For the first time, Manning and his co-authors offered a theory to account for the origin of the sex differences and individual differences within the sexes observed for 2D:4D. Based on convergent findings, such as the early emergence of sex differences in 2D:4D (which are already present in preschoolers), correlations of 2D:4D with levels of circulating sex hormones in adults, and age invariance of 2D:4D, it was hypothesised that 2D:4D could be an appropriate biomarker for the powerful, permanent (i.e., organising) masculinisation effects that are exerted through the action of prenatal androgens on the human brain, physique, and behaviour (Manning et al., 1998). Specifically, it was proposed that under the influence of prenatal testosterone, growth of the lateral fingers (specifically, of 4D) is more promoted than growth of the medial fingers (specifically, of 2D). This hypothesis of Manning has been met with considerable resonance from researchers. Given the hypothesis is correct, 2D:4D would constitute an easily and straightforwardly implementable, non-invasive, indirect means for investigating the biological bases of human personality, behavioural traits, proneness to somatic and mental disorders, and various other phenotypes. Many traits of these domains show consistent and apparently early emerging sex differences and are therefore thought to be, at least partly, influenced by effects of early exposure to sex hormones, which in turn differ noticeably between the sexes.

Following the pioneering account of Manning et al. (1998), over the past decade 2D:4D has become widely studied and popularised across scientific fields (for partial reviews, see Cohen-Bendahan, van de Beek, & Berenbaum, 2005; McIntyre, 2006; Putz, Gaulin, Sporter, & McBurney, 2004). As of this writing, the 2D:4D research literature numbers more than 300 journal articles (bibliography: Voracek & Loibl, 2009), more than 70 unpublished academic theses, and two monographs (Manning, 2002, 2008).

What is the current evidence for Manning's hypothesis? There is now a

body of more than a dozen independent lines of convergent evidence which are supportive of the hypothesis. Although the majority of this evidence is indirect and merely suggestive rather than direct and conclusive, the totality of this evidence seems persuasive. For instance, it is now known that sex and individual differences in 2D:4D indeed are already established *in utero*, where they are already obvious at the beginning of the second trimester (Malas, Dogan, Evcil, & Desdicioglu, 2006). Sex and individual differences also appear to be fairly stable during the postnatal phases of growth, as evidenced by two longitudinal studies (McIntyre, Ellison, Lieberman, Demerath, & Towne, 2005; Trivers, Manning, & Jacobson, 2006).

Several animal experimentation studies have yielded evidence that the expression of digit ratios during developmental phases can be manipulated by appropriate means. For example, testosterone, administered prenatally, alters digit ratios in birds (Romano, Rubolini, Martinelli, Alquati, & Saino, 2005), as does alcohol, which acts as an endocrine disruptor (of sex hormones, such as testosterone), when administered prenatally in rats (McMechan, O'Leary-Moore, Morrison, & Hannigan, 2004). Digit ratios in birds are changed through prenatally administered estradiol (Saino, Rubolini, Romano, & Boncoraglio, 2007), but not through postnatally administered estradiol (Forstmeier, Rochester, & Millam, 2008). Relatedly, smoking, among other things, also intervenes in endocrine regulation, as it raises levels of circulating testosterone. Accordingly, maternal smoking during pregnancy is associated with a lower (masculinised) 2D:4D in sons (Rizwan, Manning, & Brabin, 2007). In a similar vein, mothers with a high (masculinised) waist-to-hip ratio (which indicates high levels of circulating testosterone) tend to give birth to children with a low (masculinised) 2D:4D (Manning, Trivers, Singh, & Thornhill, 1999).

Another line of evidence has emerged from human twin research. It is well-known from animal research that prenatal hormone transfer occurs between embryos of different sex, and such effects may also apply to the human analogue situation, namely multiple pregnancies involving embryos of different sex. Accordingly, there is evidence that women from opposite-sex (female-male) fraternal twin pairs have lower (masculinised) 2D:4D, as compared to women from same-sex (female-female) fraternal twin pairs (van Anders, Vernon, & Wilbur, 2006; Voracek & Dressler, 2007; but see Medland, Loehlin, & Martin, 2008, for a non-replication).

Endocrinological disorders are also informative in this context. For instance, as expected, 2D:4D is low in individuals affected with congenital adrenal hyperplasia, which condition involves massive exposure to prenatal testosterone (Brown, Hines, Fane, & Breedlove, 2002; Ökten, Kalyoncu, & Yaris, 2002; but see Buck, Williams, Hughes, & Acerini, 2003, for a non-replication). 2D:4D is also low in women suffering from polycystic ovary syndrome, an endocrinologically based condition which involves hyperan-

drogenisation (Cattrall, Vollenhoven, & Weston, 2005). Brain morphometry may likewise be informative in this context. As an example, a male-typed pattern of volumetric right-left differences in the hippocampus is associated with lower (more male-typed) 2D:4D in women (Kállai, Csathó, Kövér, Makány, Nemes, Horváth et al., 2005). Further, genetically based sensitivity to testosterone is given through functional variants in the androgen receptor gene, located on the X chromosome. These gene polymorphisms influence the transcription activity of androgen receptors, and higher-activity variants of the androgen receptor gene were found to correspond to lower (masculinised) 2D:4D in men (Manning, Bundred, Newton, & Flanagan, 2003). Digit ratios may also be associated with finger-ridge counts (Manning, 2002, pp. 9-11). This is a dermatoglyphic trait which also is sexually differentiated and fixed prenatally and therefore thought to be hormonally influenced. The perhaps most direct evidence in support of Manning's hypothesis has come from a human amniocentesis study. This study found a higher (masculinised) testosterone-estradiol ratio in the amniotic fluid to be associated with a lower (masculinised) 2D:4D in the subsequently born children (Lutchmaya, Baron-Cohen, Raggatt, Knickmeyer, & Manning, 2004).

Up to now, there has been only one study of digit ratios and musical ability (Sluming & Manning, 2000; for a 2D:4D study using musical stimuli, see Millet & Dewitte, 2007). Sluming and Manning (2000), in their study of elite orchestra musicians, reported a lower (more male-typed) 2D:4D in musicians than in controls from the local general population, and further an association of higher musical-ability rankings with lower 2D:4D in the same sample of professional orchestra musicians. Although this study was one of the very first published reports of modern 2D:4D research (following the initial publication of Manning et al., 1998, two papers appeared in 1999: Manning et al., 1999; Martin, Manning, & Dowrick, 1999), and although an entire chapter of the first book-length treatment of 2D:4D research was dedicated to the reporting and discussion of this study (Manning, 2002, pp. 115-125), neither of the two findings have been replicated or extended to non-musicians.

More generally, lack of replication efforts as well as attempts to generalise initial findings have repeatedly been noted in critical discussions of 2D:4D research, along with concerns of possible publication bias in this research field (Putz et al., 2004; Vehmas, Solovieva, & Leino-Arjas, 2006). Therefore, the aim of the present research was to test whether the second finding of Sluming and Manning (2000), namely associations of musical abilities with digit ratios, is generalisable to the general population of non-musicians. Following the prior study, it was hypothesised that higher musical ability should correspond to lower (masculinised) digit ratios, i.e., negative correlations were expected.

The rationale for this research hypothesis and its direction is given

through the following considerations. Contemporary Darwinian (i.e., evolutionary psychological) theorising with regard to the existence of music emphasises some obvious parallels between the production of human music and the songs in animal species (Miller, 2000a, 2000b). Both appear to be explicable within the framework of sexual selection (as opposed to natural selection) of evolutionary theory, specifically, with intrasexual selection. For males, intrasexual selection is primarily about male-male competition for sexual access to females. Miller (2000a) has assembled ample evidence suggesting that music production and performance are important display traits in human courtship and mating behaviour. Human display traits (paralleling the ornamentations seen throughout the animal kingdom) primarily signal mate quality and reproductive fitness, which in turn are perceived as attractive by the other sex. Such cross-species congruences support biological interpretations of music production and performance (Sluming & Manning, 2000).

More generally, a number of findings from 2D:4D research are suggestive for the hypothesis that 2D:4D may be a correlate of display traits that signal mate quality and reproductive fitness. This includes evidence for associations of 2D:4D with men's hand-grip strength (Fink, Thanzami, Seydel, & Manning, 2006), with men's courtship behaviour (Roney & Maestripieri, 2004) and sporting ability and success (about a dozen studies are reviewed in Voracek, Reimer, Ertl, & Dressler, 2006), with women's perception of men's dance (Fink, Seydel, Manning, & Kappeler, 2007), with hand attractiveness (Manning, 2002, pp. 47-50; Saino, Romano, & Innocenti, 2006; Voracek & Pavlovic, 2007), and with wearing of wedding rings (Manning, 2002, pp. 51-52; but see Voracek, 2008a, for a non-replication).

By its design, the present research on 2D:4D and musical ability, taken as a display trait, expanded the only predecessor study (Sluming & Manning, 2000) in two specific ways. First, it is known that not only 2D:4D is sexually differentiated. Other finger-length ratios of the human hand show sex differences as well. However, whereas single digit ratios other than 2D:4D have occasionally been included in research reports (e.g., the 3D:4D ratio; McIntyre, Cohn, & Ellison, 2006; McIntyre et al., 2005), only a few studies (Manning, Callow, & Bundred, 2003; McFadden & Shubel, 2002; McFadden, Westhafer, Pasanen, Carlson, & Tucker, 2005; Stevenson, Everson, Williams, Hipskind, Grimes, & Mahoney, 2007; Trivers et al., 2006; Voracek & Offenmüller, 2007) have investigated all six possible digit ratios in the human hand (2D:3D, 2D:4D, 2D:5D, 3D:4D, 3D:5D, and 4D:5D). This systematic approach was therefore adopted in the present research.

Second, it has been noted that absolute finger length may reflect pubertal-adolescent testosterone levels, because sex differences therein are negligible before onset of puberty, but very large in adulthood (Jackson, 2008). Of note,

absolute finger length is not merely a proxy for adult height; rather, the correlations are only moderately positive. Up to now, very few 2D:4D studies have also investigated measures of absolute finger length (Jackson, 2008; Lippa, 2006; Voracek & Pavlovic, 2007). Therefore, mean finger length (of 2D, 3D, 4D, and 5D) was also included in the present research.

Methods

Participants

Sixty male and 64 female self-reported heterosexual young adults, all of them native Austrians, volunteered to participate in this research. There are known population differences (Manning, Barley, Walton, Lewis-Jones, Trivers, Singh et al., 2000) as well as sexual orientation differences in 2D:4D (McFadden, Loehlin, Breedlove, Lippa, Manning, & Rahman, 2005; Voracek, Manning, & Ponocny, 2005), so recruitment of samples homogeneous with respect to these variables is of importance. Ages in the sample ranged from 18 to 35 years ($M = 23.5$, $SD = 3.9$ years). Individuals reporting hearing impairments, hand or finger injuries, and professional musicians or music students were not eligible for study participation.

Measures

Basic music-related perceptual abilities were assessed with the German edition (Butsch & Fischer, 1966) of the revised *Seashore Test for Musical Talent* (Seashore, 1919; 1939, 1960; see also Saetveit, Lewis, & Seashore, 1940). This long-established and widely used psychometric instrument assesses musical talent and ability in children as well as in adults. Although it was devised during the early days of music psychology and psychometric testing, it is still used nowadays, in the era of genome scans (Pulli, Karma, Norio, Sistonen, Göring, & Järvelä, 2008) and neuroscience (Milovanov, Houttilainen, Välimäki, Esquef, & Tervaniemi, 2008). The test has six subscales (Pitch, Loudness, Rhythm, Time, Timbre, and Tonal Memory), which are comprised of 50, 50, 30, 50, 50, and 30 items, respectively. Each item consists of two acoustic stimuli, and the number of correct items are summed up to yield the respective subscale score. In the six subtests, respondents have to compare the second stimulus to the first one, namely whether it is higher *vs.* lower (Pitch subtest: 2 to 17 Hz difference between stimuli), louder *vs.* quieter (Loudness subtest: 0.5 to 4 dB difference between stimuli), longer *vs.* shorter (Time subtest: 0.05 to 0.3 s difference between stimuli), of the same *vs.* of different rhythm (Rhythm subtest: same or differ-

ent rhythmic patterns, comprising 5 to 10 tones), of the same *vs.* of different timbre (Timbre subtest: modulation of third and fourth overtones or none), or whether it represents the same *vs.* a different tonal sequence (Tonal Memory subtest: comparison of two series of 3 to 5 tones, wherein the position of the one tone being different has to be determined).

Following standard practice of digit ratio research (Voracek, Manning, & Dressler, 2007), flatbed-scanned images of participants' right and left hands in palmar view were produced. It is well-known that 2D:4D is more sexually differentiated in the right than in the left hand, and correlations between 2D:4D and candidate traits frequently are stronger for the right than for the left hand (Manning, 2002). These related lines of evidence are consistent with the reasoning of testosterone-dependent physical features to be more strongly expressed on the right than on the left body side (Tanner, 1990). For these reasons, both right-hand and left-hand digit ratios were ascertained.

From high-resolution laser printouts of the image files of the hands, one experienced investigator (J.P.) measured the length of index, middle, ring, and little fingers two times, using a digital vernier calliper measuring to 0.01 mm (Mitutoyo Ltd., Andover, Hampshire, U.K.; Model 500-191U). The middle of the finger flexion crease proximal-most to the palm was the lower measurement landmark, and the respective fingertip (excluding possibly protruding fingernails) the upper measurement landmark.

Procedure

Participants were tested individually or in small groups (up to four individuals) in a quiet facility. After reporting basic demographic information, the full version of the *Seashore Test* battery was administered. Its acoustic stimuli (stored on an audiotape) were administered via a tape recorder, the sequence of subtests (as listed above) was held constant across participants, and verbal instructions were provided before each subtest. After completing the *Seashore Test*, the hand images were taken, and participants were then thanked and debriefed.

Data analysis

Individual item responses on the *Seashore Test* were summed up to yield six subtest scores and a total test score. Averaged finger-length measurements were used to calculate right-hand (R2D:3D, R2D:4D, etc.) and left-hand digit ratios (L2D:3D, L2D:4D, etc.). Intraobserver repeatabilities of finger-length measurements were quantified with average-score intraclass correlation coefficients (*ICC*), according to a two-way mixed-effects model with absolute-agreement definition (Voracek et al., 2007).

Results

Sex differences in and reliabilities of study variables

Descriptive statistics and the results of tests for sex differences on the variables under study, along with the respective repeatability or reliability figures, are shown in Table 1. The reproducibility of averaged finger length was very high

Table 1
Sex differences in and reliability of finger-length measures and basic musical abilities

	Men (n = 60)		Women (n = 64)		t	p	d	Rel
	M	SD	M	SD				
<i>Finger-length measures</i>								
R2D:3D	0.879	0.024	0.883	0.023	-1.02	.31	-0.17	.933
R2D:4D	0.941	0.029	0.955	0.030	-2.76	.007	-0.47	.942
R2D:5D	1.170	0.037	1.202	0.058	-3.65	< .001	-0.65	.933
R3D:4D	1.070	0.030	1.082	0.025	-2.27	.03	-0.44	.928
R3D:5D	1.332	0.050	1.361	0.068	-2.73	.007	-0.48	.941
R4D:5D	1.244	0.039	1.258	0.048	-1.74	.08	-0.32	.919
L2D:3D	0.881	0.023	0.882	0.025	-0.17	.87	-0.04	.951
L2D:4D	0.950	0.026	0.962	0.032	-2.20	.03	-0.41	.937
L2D:5D	1.193	0.043	1.217	0.058	-2.62	.01	-0.47	.955
L3D:4D	1.079	0.027	1.091	0.027	-2.50	.01	-0.44	.935
L3D:5D	1.356	0.061	1.382	0.075	-2.12	.04	-0.38	.972
L4D:5D	1.257	0.046	1.267	0.055	-1.08	.28	-0.20	.939
Average finger length	72.28	3.78	66.42	3.56	8.89	< .001	1.60	.998
<i>Musical ability measures</i>								
Seashore – Pitch	35.85	6.49	37.23	5.26	-1.31	.19	-0.23	.78
Seashore – Loudness	43.88	2.99	43.55	2.78	0.65	.52	0.11	.47
Seashore – Rhythm	27.27	2.11	27.17	1.84	0.27	.79	0.05	.46
Seashore – Time	41.55	4.15	41.28	4.18	0.36	.72	0.06	.64
Seashore – Timbre	44.37	3.50	42.53	4.09	2.68	.008	0.48	.70
Seashore – Tonal memory	24.68	4.67	24.89	4.50	-0.25	.80	-0.05	.84
Seashore – Total score	217.60	15.20	216.66	14.04	0.36	.72	0.06	.86

Note. t = t test statistic, with associated p value (two-tailed); d = Cohen's d effect-size metric (male mean minus female mean, divided by square root of weighted mean of group variances). Rel = intraclass correlation coefficients for finger-length measures, Cronbach α for musical ability measures. Absolute finger length is in mm.

(*ICC* = .998), and finger-length ratios were also highly repeatable, with the *ICCs* ranging from .919 to .972. Internal scale consistencies for the *Seashore Test* subscales were, for the most part, satisfactory or acceptable, except for the Loudness and Rhythm subtests (Cronbach α = .47 and .46, respectively), whilst the internal reliability of the total *Seashore Test* score was excellent (α = .86).

As for sex differences on the finger-length measures, a set of normative findings, known from the literature (Manning, 2002; Voracek & Offenmüller, 2007), replicated in this sample as well. Men invariably had lower digit ratios than women. These sex differences in digit ratios were statistically significant with the available sample size, except for 2D:3D (in both hands) and 4D:5D (in the left hand). Except for 3D:4D, the sex effect seen in the digit ratios was somewhat more pronounced for the right hand than for the left hand. Digit ratios calculated from non-adjacent fingers were somewhat larger than those calculated from adjacent fingers. In both hands, the largest sex difference was observed for 2D:5D rather than for the classic 2D:4D, and effect sizes for sex differences in digit ratios ranged from small to medium size.

Also as expected, sex differences in absolute finger length were very large. Of note, they were invariably larger for 4D than for 2D (details omitted), which is the basis for the sex difference observed in 2D:4D. Men exceeded women in five of the six *Seashore Test* tasks (except for the Pitch subtest). However, these sex differences generally were of small size and only in one instance statistically significant (for the Timbre subtest: two-tailed p = .008, d = 0.48). Also, the sex difference on the total *Seashore Test* score was statistically not significant (p = .72) and of negligible size (d = 0.06, favouring men). All subscale scores of the *Seashore Test* were strongly positively correlated with total test scores and positively interrelated among themselves (except for the Timbre subscale, which was largely disassociated from the other subscales; Table 2).

Table 2
Associations of Seashore Test subscales

	Pitch	Loudness	Rhythm	Time	Timbre	Tonal memory	Total score
Pitch							
Loudness	.33***						
Rhythm	.30**	-.03					
Time	.34***	.28**	.20*				
Timbre	.12	.04	.21*	.17			
Tonal memory	.34***	.23*	.39***	.28**	.29**		
Total score	.75***	.49***	.49***	.64***	.49***	.71***	

Note. Table entries are Pearson r coefficients.

* = p < .05; ** = p < .01; *** = p < .001 (two-tailed).

Sex-specific associations of finger-length measures with musical ability

The results of this correlational analysis are set out in Table 3. Briefly, the following pattern emerged: first, the associations between total *Seashore Test* scores with either digit ratios or mean finger length were throughout not significant, neither among men nor among women. Second, all associations with musical abilities involving the classic 2D:4D ratio were also not significant.

Table 3
Sex-specific associations of finger-length measures with basic musical abilities

Men	Women														
	Pitch	Loudn	Rhythm	Time	Timbre	Tonal	Total		Pitch	Loudn	Rhythm	Time	Timbre	Tonal	Total
R2D:3D	-.12	.05	-.13	.03	-.18	.06	-.08		.02	.08	.07	-.21	.01	.07	-.01
R2D:4D	-.03	.13	.13	.22	-.10	-.01	.07		-.14	.06	.01	-.21	-.02	.13	-.07
R2D:5D	.10	.07	.31*	.24	-.02	.04	.17		-.20	.08	-.11	-.02	.15	-.02	-.04
R3D:4D	.08	.10	.27*	.22	.05	-.06	.14		-.21	-.01	-.07	-.04	-.04	.09	-.09
R3D:5D	.17	.02	.35**	.19	.11	-.01	.20		-.20	.04	-.14	.09	.14	-.05	-.04
R4D:5D	.13	-.06	.18	.03	.09	.05	.11		-.14	.06	-.13	.14	.21	-.13	.01
L2D:3D	-.10	.08	-.12	.17	-.15	-.04	-.04		.09	.19	.21	-.04	.13	.08	.15
L2D:4D	-.21	.12	-.10	.16	-.14	-.13	-.11		-.16	.04	.10	-.14	.09	.10	-.02
L2D:5D	-.06	.20	.16	.21	-.11	-.09	.04		-.26*	.03	-.04	-.04	.14	-.11	-.10
L3D:4D	-.13	.05	.01	-.01	.01	-.10	-.07		-.32*	-.16	-.11	-.13	-.03	.04	-.20
L3D:5D	.01	.12	.20	.07	.01	-.04	.06		-.27*	-.07	-.14	-.02	.05	-.13	-.17
L4D:5D	.10	.10	.23	.09	.01	.01	.12		-.17	.01	-.11	.05	.08	-.19	-.10
FL	-.09	.20	-.28*	-.32*	-.01	-.02	-.13		.31*	.05	-.01	.08	.01	.02	.16

Note. Table entries are Pearson r coefficients. Loudn = Loudness, Tonal = Tonal memory; FL = average finger length.
* = $p < .05$; ** = $p < .01$ (two-tailed).

Third, there were some significant associations (according to two-tailed tests) between specific musical abilities and several digit ratios among both men and women. As for men, Rhythm scores were significantly positively correlated with 2D:5D, 3D:4D, and 3D:5D of the right hand (but not the left hand). As for women, Pitch scores were significantly negatively correlated with 2D:5D, 3D:4D, and 3D:5D of the left hand (but not the right hand). All in all, this correlational pattern would suggest that some higher (feminised or demasculinised) digit ratios in men, but some lower (masculinised or defeminised) digit ratios in women, correspond to some facets (i.e., *Seashore* subtests) of higher musical abilities. That is, the pattern (i.e., the direction of the associations) differed between men and women and was not theory

compliant for men. Apart from that, the pattern was clearly erratic with regard to which musical abilities and which digit ratios of which hand were involved in and contributed to the significant associations, and, as mentioned above, significant correlations neither involved the classic 2D:4D ratio nor total *Seashore Test* scores. The few significant associations with musical ability scores were not more likely to occur for right-hand than for left-hand digit ratios.

Fourth, there were a number of significant associations between specific musical abilities and absolute finger length, again among both men and women. Specifically, as for men, Rhythm and Time scores were significantly negatively associated with average finger length. As for women, Pitch scores were significantly positively associated with average finger length. All in all, this pattern would suggest that shorter (more female-typed) finger length in men, but longer (more male-typed) finger length in women, correspond to some facets of higher musical abilities. Again, the direction of these associations was different for men and women and not theory compliant for men. In addition, the pattern seemed erratic with respect to which musical abilities were involved in and contributed to the significant associations. Also, the pattern of significant associations did not involve total *Seashore Test* scores.

Discussion

The results of this first study that examined the associations of putative markers for prenatal and pubertal-adolescent androgen levels with musical ability among adult non-musicians contain a number of points of interest. For women, better pitch and time discrimination of acoustic stimuli was associated with lower (masculinised) digit ratios, and better pitch discrimination was associated with longer (masculinised) fingers. These correlations were directionally consistent with theory, expectation, and related prior findings (Miller, 2000a; Sluming & Manning, 2000). For men, results were exactly the other way round and thus not theory compliant. Specifically, better rhythm discrimination was associated with higher (feminised) digit ratios, and better performance on rhythm and time discrimination was associated with shorter (feminised) fingers.

For both sexes, there were very few significant associations of musical abilities with the finger-length ratios, and these effects generally were of modest size. Such findings are not uncommon in digit ratio research. It seems that more substantial effects cannot be obtained for correlations of simple anthropometric measures with target traits, and that digit ratio is a “noisy” indicator that may produce inconsistent evidence within studies and

contradictory findings across studies.

Of interest, basic musical abilities, as assessed with the *Seashore Test* battery, did not turn out to be noticeably sex-typed. Although men exceeded women on most of the tasks, sex differences were, with the exception of timbre discrimination, negligible. Further, no significant associations involving either total *Seashore Test* scores or the classic 2D:4D ratio emerged. This may suggest that this line of inquiry could benefit more from investigating specific rather than broad abilities and, in addition, other digit ratios rather than solely the classic 2D:4D. Relating to the lack of sex differences in the musical ability measures observed in this sample, it is noted that the existence and magnitude of differences between the sexes in this set of variables could not impact the analysis, as this throughout was a within-sex correlational analysis.

An important limitation of this study is the large number of statistical tests applied (Table 3). It is clear that the few significant sex-specific correlations between the various finger-length measures and musical abilities would not survive adjustments for multiple statistical tests. However, since the subsets of variables under study (digit ratios and musical abilities) were positively interrelated among themselves, such adjustments of significance levels are difficult to apply, may not be appropriate (Nakagawa, 2004; Perneger, 1998), and were thus waived. It is emphasised that the total number of correlations that were significant was indistinguishable from the occurrence of false-positive findings when in fact there were no real effects. Only replication of the present findings will allow to reliably disentangle such spurious effects from possibly real ones.

One further study limitation was that although average finger length and height are positively related (albeit only moderately so), this relationship was not controlled for. In a recent 2D:4D study (Voracek, Pum, & Dressler, in press), it was shown that associations of finger length with target variables remained virtually unchanged with controls for height. As a consequence of this null effect of height as a covariate, it was not included in the data collection for the present study, although in hindsight it would perhaps have been safer having done so.

Whereas for women the current findings were theory compliant, in that they seemed to extend and generalise previous evidence, those for men were clearly inconsistent and at variance with what is known on the topic (Sluming & Manning, 2000). Conflicting findings such as these are not uncommon in 2D:4D research (Putz et al., 2004). As for one example, starting with the work of Manning, Baron-Cohen, Wheelwright, and Sanders (2001), a number of studies have presented evidence for a lower (masculinised) 2D:4D in children affected by autism-spectrum disorders, relative to matched healthy population controls (for a review of studies, see Voracek, 2008b).

However, subsequent research, based on a reasonably large sample, was unable to demonstrate significant associations of digit ratios with psychometrically measured autistic-like traits in the healthy general adult population (Voracek & Dressler, 2006). This outcome appears akin to the present study findings: whereas in the predecessor study (Sluming & Manning, 2000) negative correlations between musical-ability rankings and 2D:4D could be ascertained in a predominantly male sample of elite orchestra musicians, the present study sought to extend and generalise this evidence, but obtained no such negative correlations among male non-musicians from the general population. This present finding for men is seemingly contradictory, although it could potentially be resolved by demonstrating that it is produced through interactions of sex and threshold effects in both testosterone exposure (which prenatally as well as from puberty onwards differs markedly between the sexes) and level of musical ability (professional musicians *vs.* non-musicians). This issue remains an important agenda to address for future research. A further point to elucidate is which types of acoustic discrimination abilities, if any, are most consistently and strongly related to anthropometric markers for testosterone levels and why. One reviewer of this paper suggested that, to the extent that 2D:4D truly is a correlate of display traits signalling mate quality and reproductive fitness, one could expect associations between 2D:4D and the display trait of musical abilities only to emerge in actual mating contexts. This idea contains a diversity of fruitful starting points for further research along these lines. The approach seems already foreshadowed by evidence for associations of men's 2D:4D with their courtship behaviour in social interactions with women (Roney & Maestripieri, 2004) and with women's perception of men's dance (Fink *et al.*, 2007).

In sum, the current data yielded little support for the assumption that within-sex interindividual variation in basic musical abilities of adult non-musicians is partly influenced by biologically based factors, specifically, by prenatal or pubertal-adolescent sex-hormonal effects. Whereas associations were directionally opposed to theory and expectation among men, among women masculinised digit ratios and finger length corresponded to higher musical abilities. Hence this sexually differentiated pattern awaits replication or clarification.

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