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Sexual Orientation and the Second to Fourth Finger Length Ratio: A Meta-Analysis in Men and Women

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The ratio of the lengths of the second and fourth fingers (2D:4D) may serve as a marker for prenatal androgen signaling. Because people are typically unaware of their 2D:4D, its use allows possible effects of early sex hormone regimes and socialization to be disentangled. We conducted a meta-analysis on relationships between 2D:4D and sexual orientation in men and women in 18 independent samples of men and 16 independent samples of women. Collectively, these samples comprised 1,618 heterosexual men, 1,693 heterosexual women, 1,503 gay men, and 1,014 lesbians. In addition to identifying the normative heterosexual sex difference in 2D:4D for both hands, we found that heterosexual women had higher (more feminine) left- and right-hand 2D:4D than did lesbians, but we found no difference between heterosexual and gay men. Moderator analyses suggested that ethnicity explained some between-studies variation in men. These results add to a literature suggesting that early sex hormone signaling affects sexual orientation in women, and highlight the need for further research exploring the relationships among 2D:4D, sexual orientation, and ethnicity in men.

Keywords: 2D:4D, androgen, sexual differentiation, sex hormones, sexual orientation

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Sexual orientation is one of the most sexually differentiated psychological traits: About 97–98% of men are primarily attracted to women and a similar proportion of women are primarily attracted to men (Laumann, Gagnon, Michael, & Michaels, 1994; Wellings, Field, Johnson, & Wadsworth, 1994). The size of this sex difference is very large: approximately 6 standard deviations (Hines, 2004). In nonhuman vertebrates, testicular hormones play a major role in organizing sex differences in the brain and behavior (Morris, Jordan, & Breedlove, 2004; Zuloaga, Puts, Jordan, & Breedlove, 2008), and this appears to be true of humans as well (Hines, 2004; Kimura, 1999). Thus, it is reasonable to expect androgens to play a role in the development of sexual orientation in humans.

Several lines of evidence support this inference. For example, male infants with apparently normal or sex-typical prenatal androgen exposure who have undergone gender reassignment to female shortly after birth (e.g., to resolve abnormal differentiation of the genitals or damage to the penis requiring its removal, as in a condition called cloacal exstrophy) appear to report sexual attraction to females (Mustanski, Chivers, & Bailey, 2002; Reiner & Gearhart, 2004). This suggests that prenatal developmental events, including those dependent on sex hormones, have effects on sexual orientation that persist despite discordance with the assigned gender role. In addition, 46,XY individuals with complete androgen insensitivity syndrome (CAIS) are similar to, if not indistinguishable from, unaffected female controls in their sexual orientation (Hines, Ahmed, & Hughes, 2003; Money, Schwartz, & Lewis, 1984; Wisniewski et al., 2000). Finally, females with congenital adrenal hyperplasia (CAH), in which the adrenal glands produce an excess of prenatal androgen, are several times likelier than unaffected females to experience bisexual/lesbian fantasy or to identify as bisexual or lesbian (Hines, Brook, & Conway, 2004; Meyer-Bahlburg, Dolezal, Baker, & New, 2008; Money et al., 1984; Zucker et al., 1996).

Each of these lines of evidence, however, is confounded by possible socialization effects. For example, sexual orientation in individuals with CAIS is concordant with gender of rearing. Thus, the rearing environment, rather than the absence of androgen signaling in the brain, may primarily account for sexual orientation in CAIS women. In girls with CAH, it has been argued that their male-typical gender role behavior during childhood may elicit a concatenation of psychosocial experiences that differentiate them from unaffected girls, which, in turn, may influence the development

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of their sexual orientation (for an elucidation of this mediational model, see Bem, 1996). Thus, in these groups, sexual orientation that is discordant with the sex of rearing may result, in part, from differential psychosocial experiences, and thus the effects of prenatal hormones may be only indirect (but see Pasterski et al., 2005).

Another potential source of evidence regarding the role of prenatal androgen on sexual orientation is the ratio of the lengths of the second and fourth fingers (2D:4D). Males develop a lower 2D:4D than do females by the end of the first trimester of gestation (Galis, Ten Broek, Van Dongen, & Wijnaendts, 2010; Malas, Dogan, Evcil, & Desdicioglu, 2006). Because of the early fetal development of sexual dimorphism in 2D:4D, researchers have suggested that 2D:4D may be influenced by prenatal androgen, and thus may serve as a biomarker for prenatal androgen exposure (Manning, Scutt, Wilson, & Lewis-Jones, 1998; Williams et al., 2000). Although multiple factors likely contribute to variation in 2D:4D (Saino, Rubolini, Romano, & Boncoraglio, 2007; Yan, Bunning, Wahlsten, & Hurd, 2009), subsequent research has supported the notion that 2D:4D reflects early androgens: A more masculine digit ratio has been associated with CAH (Brown, Hines, Fane, & Breedlove, 2002; Ciumas, Linden Hirschberg, & Savic, 2009; Ökten, Kalyoncu, & Yaris, 2002; but see Buck, Williams, Hughes, & Acerini, 2003), fetal testosterone/estrogen levels (Lutchmaya, Baron-Cohen, Raggatt, Knickmeyer, & Manning, 2004), as well as a genetic predictor of androgen sensitivity (Manning, Bundred, Newton, & Flanagan, 2003). Moreover, XY individuals with androgen insensitivity syndrome have a more feminine 2D:4D than that of typical men and one similar to that of typical women (Berenbaum, Bryk, Nowak, Quigley, & Moffat, 2009). Females exposed to elevated prenatal testosterone due to having a male cotwin also exhibit masculinized digit ratios (van Anders, Vernon, & Wilbur, 2006). Digit ratios are also sexually dimorphic in avian animal models (Burley & Foster, 2004; Leoni, Rubolini, Romano, di Giancamillo, & Saino, 2008), and experimental prenatal testosterone treatment has been shown to masculinize digit ratios in birds (Romano et al., 2005).

People are highly unlikely to be aware of their own 2D:4D; hence, this marker may allow researchers to explore associations with prenatal androgens that are not confounded by possible socialization effects. In addition, because the evidence for prenatal hormonal effects on human sexual orientation is entirely correlational, disparate but convergent lines of evidence are important in helping to rule out alternative explanations for these correlations. Indeed, multiple groups of researchers have examined associations between 2D:4D and sexual orientation in both sexes. However, results of these studies are mixed, especially for males; in general, failures to replicate significant correlations between 2D:4D and various traits are common (Putz, Gaulin, Sporter, & McBurney, 2004), highlighting the need for meta-analytic studies (e.g., Honekopp, Bartholdt, Beier, & Liebert, 2007; Puts, McDaniel, Jordan, & Breedlove, 2008). Several years ago, it was already apparent that findings were mixed with regard to the relationships between sexual orientation and 2D:4D (McFadden et al., 2005). Since then, more studies with mixed findings have been published. Quantitative meta-analysis can help identify sources of variation between studies and gauge the strength of particular associations and has replaced narrative review as the standard method of review. We therefore performed a meta-analysis of all published studies that examined 2D:4D in heterosexual and gay men or heterosexual and lesbian women.

Method

Selection of Studies

The principal method used for locating studies was a search in PubMed, PsychInfo, PsychLit, and ProQuest for articles with quantitative data on 2D:4D and sexual orientation. Combinations of key words in the following groupings were used: (a) *2D:4D, digit ratio, finger ratio*; (b) *sexual orientation, sexual preference, heterosexual*, homosexual*, gay, lesbian, straight*. Second, the ancestry method was used in which references were retrieved from articles obtained using the principal search method (Phares & Compas, 1992). Finally, we looked for studies that were presented at scientific sex research meetings. To our knowledge, our search identified the entire body of published research on 2D:4D and sexual orientation.

Inclusion Criteria

To be included in the meta-analysis, a study had to include data on 2D:4D in heterosexual and gay men or heterosexual and lesbian women. We excluded studies that did not have data for gay and heterosexual persons separately. If a study did not report the mean digit ratio and corresponding standard deviation, we contacted the corresponding author to obtain this information. In addition, only studies that employed a trained researcher to measure digit length were included in the meta-analysis. Although self-measurements correlate significantly with experimenter measurements using Vernier calipers or computer-assisted measurements of scans, these correlations are not especially strong (Burriss, Little, & Nelson, 2007). Self-measurements of right-hand, compared with left-hand, digit length correlate less well with experimenter measurements, presumably because the majority of persons are right-handed and find it difficult to measure the digits of their right hand. This is especially problematic because many of the associations between 2D:4D and behavioral measures are strongest for right-hand digit ratio. In implementing this criterion, we excluded of a large-scale Internet study (Manning, Churchill, & Peters, 2007) in which participants measured their own digit length. Manning et al. (2007) reported lower effect sizes for the sex difference in digit ratio compared with other studies: $g = -.20$, $p < .001$, for the right hand, and $g = -.17$, $p < .001$, for the left hand. Given that the sex difference is a well-established finding, these lower than usual effect sizes suggest the presence of error variance, probably due to measurement error.

Study Sample

Results from 34 independent samples met the inclusion criteria—the relationship between 2D:4D and sexual orientation was investigated in 18 samples of men and 16 samples of women. These samples represented a total of 21 studies published between September 2000 and August 2009. Most studies contributed both male and female samples to our meta-analysis (only six studies focused exclusively on men or women). Given that we frequently analyzed male and female samples separately, we will use the term *sample* rather than *study* from here on. In total, there were 1,618 heterosexual men (sample size range: 7 to 349), 1,693 heterosexual women (sample size range: 7 to 705), 1,503 gay men (sample size range: 5 to 460), and 1,014 lesbians (sample size range: 2 to 468). Across these studies, 13 samples also examined differences in 2D:4D between heterosexual men and heterosexual women. Of the 18 samples that comprised gay and heterosexual men, sample sizes ranged from 61 to 809 (M = 172). Of the 16 samples that comprised lesbian and heterosexual women, sample sizes ranged from 58 to 1,173 (M = 181).[1]

Moderator Variables

Study variables were coded by the first author. The entire data set was then checked for errors (separately) by one research assistant and the fourth author. The research assistant was blind to the study hypotheses. Both the first and fourth authors examined the coded data set to resolve any discrepancies. We also coded for theoretically and methodologically relevant variables and study characteristics that might moderate the magnitude of the difference in 2D:4D between gay and lesbian persons and heterosexuals. Moderator variables included four categorical variables (sex, geographic location, digit measurement mode, and the extent to which a person identifies as exclusively gay or heterosexual, hereafter termed *exclusivity of preference*) and two continuous variables (age and ethnicity). Rationale for coding ethnicity as a continuous variable is given below.

Sex. Biological sex of the sample was coded as *male* or *female*. This moderator variable was used to examine whether the relationship between 2D:4D and sexual orientation differed for men and women.

Geographic location. Samples were coded as either *North American* or *European*. One sample in Manning and Robinson (2003) comprised participants from several nations across continents; thus, geographic location was not coded for this particular sample.

Digit measurement. We coded for whether finger length was directly measured from the hand (*direct measurement*) or from photocopies, scans, or ink prints of hands (*nondirect measurement*).

Exclusivity of preference. Samples were coded as either exclusively heterosexual versus gay (*exclusive*) or exclusively heterosexual versus gay/bisexual (*nonexclusive*). Samples were coded as *exclusive* when, depending on how sexual orientation was assessed (see online supplemental Table S1), either self-labeled bisexuals were excluded or participants with intermediate scores on a Kinsey-like dimensional attraction scale (reflecting bisexuality) were excluded. Only self-labeled heterosexual or gay persons or those with very high or low Kinsey attraction scores (reflecting predominant or exclusive attraction toward the same or other sex) were included. Samples were coded as *nonexclusive* when bisexual persons (based on self-identification or intermediate Kinsey scores) were grouped among the gay persons. We excluded one sample that grouped bisexual persons among heterosexual persons (Kraemer et al., 2006) in the moderator analyses because we were interested in the exclusivity of the gay category.

Age. The mean ages of heterosexual men, heterosexual women, gay men, and lesbians were coded. For all participants, mean ages were 27.88 (heterosexual men), 28.44 (heterosexual women), 32.70 (gay men), and 31.46 (lesbians) years.

Ethnicity. Given that 2D:4D is known to vary with ethnicity (Manning et al., 2000; Manning, Stewart, Bundred, & Trivers, 2004), participant ethnicity was reported in most studies (n = 16). However, when this information was not reported, we contacted authors to obtain an ethnic breakdown. Data on ethnicity were not collected (not recorded) in two studies (P. A. Hall & Schaeff, 2008; van Anders & Hampson, 2005), and ethnicity estimates were available for five studies (Kraemer et al., 2006, 2009; Putz et al., 2004; Wallien, Zucker, Steensma, & Cohen-Kettenis, 2008; Williams et al., 2000). Because the ethnicity of non-White participants was variable, it was impossible to examine any one particular non-White ethnic group. Thus, we focused on the extent to which samples were composed of more or fewer White participants. Using a 0–100 scale, we coded for the percentage of White participants in each sample. One study (Robinson & Manning, 2000, Sample 2) was excluded from ethnicity analyses because the sample was cross-cultural and ethnicity was highly variable.

Meta-Analytic Strategy

In the current meta-analysis, the effect size analyzed was the standardized mean difference (Hedge's g), which expresses the mean difference in 2D:4D between heterosexual and gay persons. Hedge's g was used because it adjusts for differences in sample size. Meta-analyses were conducted on effect sizes using a random effects model that considers the presence of moderators a possibility (Hunter & Schmidt, 2000). Employing a random effects model is appropriate for these data given the variability of the effect size distribution, suggesting the presence of moderators.

Prior to exploring the relationship between digit ratio and within-sex variation in sexual orientation, we examined sex differences in 2D:4D between heterosexual men and heterosexual women. For each study that assessed the mean digit ratio in male and female heterosexuals, we calculated separate average effect sizes (expressing the mean 2D:4D differences between male and female heterosexuals). We then analyzed data across these studies to estimate the population effect size.

For the main meta-analysis, we calculated average effect sizes (expressing the mean 2D:4D differences between gay and heterosexual persons) for each sample. We analyzed data across samples to estimate the population effect size and variables that might moderate the strength of the effect sizes; this was done separately for men and women. For the analysis of the relationship between sexual orientation and 2D:4D, we conducted two analyses: one in which we examined the difference in digit ratio between gay and heterosexual men and another in which we examined the difference between lesbian and heterosexual women. We estimated the population effect size by the average effect size (Hedge's g). In

[1] In Kraemer et al. (2009) and Wallien et al. (2008), homosexual participants also had gender identity disorder (GID). In Kraemer et al. (2006), heterosexual participants were first compared with homosexuals without GID, and the same heterosexual participants were then compared with a different group of homosexual participants with GID in Kraemer et al. (2009). This overlapping heterosexual group was not included in the sample size count; however, we considered the comparison between heterosexuals and GID homosexuals as an additional sample.

calculating the average effect size, each effect size was weighted by its sample size. Weighting was applied because large sample sizes should approximate the population effect size more precisely than smaller samples. The resulting population effect sizes can be interpreted using Cohen's (1992) recommendations that Hedge's *g*s of .20, .50, and .80 represent small, medium, and large effect sizes, respectively. The homogeneity estimate (Q) measured the likelihood that, within each analysis, effect size variation was not due to sampling error. A significant Q value indicates that effect sizes are heterogeneous, suggesting the presence of moderators and thus warranting a search for them.

In addition to estimating the mean population difference in 2D:4D, we conducted two analyses that would provide an indication of publication bias: Rosenthal's (1991) fail-safe N and a "trim and fill" analysis (Duval & Tweedie, 2000). Rosenthal's fail-safe N determines the number of null results that would be required to bring the mean effect size to zero. A trim and fill analysis determines where missing studies are likely to fall on the basis of an analysis of study size as a function of effect size. In the absence of publication bias, effect sizes should be distributed symmetrically to the left and right of the combined effect. If smaller studies tend to be distributed to one side of the combined effect, then this suggests the presence of missing studies on the other side. Trim and fill adds inferred effect sizes to the analysis, and then recomputes the combined effect. An "omit one study" analysis was also performed. This type of sensitivity analysis determines whether the results of the meta-analysis would change through the deletion of each study individually. We also conducted separate cumulative meta-analyses for men and women to examine combined effect size trends over time.

Next, we examined moderators of the relationship between 2D:4D and sexual orientation. The first moderator analysis that we performed included male and female samples in one analysis and used sex as a moderator variable to determine whether the relation between 2D:4D and sexual orientation was different for men and women. All other moderator analyses were conducted separately for men and women. For the categorical moderating variables, namely location, digit measurement mode, and exclusivity of preference, we used categorical model procedures. In this procedure, which is analogous to an analysis of variance (ANOVA), effect sizes were grouped according to moderator variable levels, and these groups were compared. Testing yields two homogeneity estimates, a between-groups Q (Q_b) and a within-groups Q (Q_w). Much like the F statistic in ANOVA, a significant Q_b means that subgroups of effect sizes are significantly different from one another. A significant Q_w means that, within a subgroup, effect sizes are heterogeneous and substantial variability exists. If an analysis demonstrates a significant Q_b, but within-subgroup effect sizes are still heterogeneous, it may be that another moderator explains the variability within that subgroup. In such cases, results must be interpreted with caution. For the continuous moderator variables, age and ethnicity, weighted least squares regression procedures were performed to evaluate the relationship between effect size and levels of the continuous moderator variable. Weighted least squares regression is an analogue to simple linear regression, with the additional feature that each effect size is weighted by its sample size. The weighted regression analysis provides a test of model specification (Johnson & Eagly, 2000), which is indexed by the Q statistic. Q is analogous to the sum of squares in linear regression. The total Q is partitioned into a Q due to the model (Q_m) and a residual Q (Q_{res}). Q_m indicates the variability of the effect sizes that is explained by the model; Q_{res} indicates the variability of the effect sizes that is not explained by the model. Moderator variables were entered into the regression equation one at a time. All analyses were performed using Comprehensive Meta-Analysis Program Version 2.

Results

Online supplemental Table S1 provides a summary of each study included in the meta-analysis. Details include sample characteristics, digit measurement and sexual orientation assessment methods, and effect sizes (Hedge's g) comparing 2D:4D in heterosexual and gay persons. A total of 343 effect sizes were calculated, including effect sizes comparing heterosexual men and heterosexual women, gay and heterosexual men, lesbian and heterosexual women, and moderator analyses conducted separately for men and women (effect sizes were also calculated for the left and right hand separately).

Sex Differences Between Heterosexual Men and Women

Before comparing 2D:4D in gay and heterosexual persons, we examined heterosexual sex differences in 2D:4D. Thirteen samples that compared 2D:4D in heterosexual men and women were included in this analysis. Heterosexual men tended to have a lower (more typically masculine) digit ratio than did heterosexual women, $g = -.55$, $p < .001$ (right hand) and $g = -.44$, $p < .001$ (left hand); effect sizes were medium. Rosenthal's fail-safe N indicated that, for the right and left hand, respectively, 505 and 303 additional null effects would be needed to render the overall effect sizes nonsignificant at $p = .05$. Trim and fill analysis did not reveal any asymmetry in the data and did not change point estimates. Omit one study analysis produced Hedge's g values ranging from $-.55$ to $-.51$ (right hand) and from $-.46$ to $-.41$ (left hand); all values were statistically significant.

Sexual Orientation Differences: Sex as a Moderator

Next, we compared 2D:4D in gay and heterosexual persons. Using sex as a moderator variable, we examined whether the relation between digit ratio and sexual orientation differed for men and women. There was a significant moderator effect for the right hand, $Q_b(1) = 4.84$, $p < .05$, and for the left hand, $Q_b(1) = 3.96$, $p < .05$. These findings indicate a relation between digit ratio and sexual orientation for women, but not men. Lesbians had a lower (more typically masculine) digit ratio than did heterosexual women ($g = .29$, $p < .02$, for right hand; $g = .23$, $p < .02$, for left hand); these effect sizes ranged from small to medium (see online supplemental Figure S1). There was no significant difference in 2D:4D between gay and heterosexual men (see Table 1 and online supplemental Figure S2).[2] Forest plots showing effect sizes for

[2] Although we excluded Manning et al. (2007) on the basis that participants measured their own finger length, results changed minimally when we included this large sample in the meta-analysis: for men, $g = -.03$, *ns*, for right and left hand; for women, $g = .23$, $p < .01$, for right hand and $g = .18$, $p < .01$, for left hand.

Table 1
Effect Size for 2D:4D Mean Difference Between Homosexuals and Heterosexuals: Separate Analyses for Men and Women

Sex	No. studies	Hand	Hedge's g	CI	p
Men	18	Right	−.02	[−.16, .12]	.75
	17	Left	−.02	[−.17, .13]	.82
Women	16	Right	.29	[.06, .51]	.02
	15	Left	.23	[.04, .43]	.02

Note. A positive Hedge's g value indicates that homosexuals have a lower (more masculinized) 2D:4D than heterosexuals; a negative value indicates that homosexuals have a higher (more feminized) mean ratio than heterosexuals.

each sample are presented in Figures S1 and S2 for women and men, respectively.

In the case of publication bias, trim and fill analysis inferred four and five missing studies to the left of the mean in women for the right and left hand, respectively, and zero and one missing studies to the left of the mean for the right and left hand, respectively. Including these inferred studies in the analysis rendered point estimates for women of .13 (right hand) and .07 (left hand), and estimates for men of −.02 (right hand) and −.03 (left hand). Despite this reduction in point estimates for women, Rosenthal's fail-safe N suggested that lesbian and heterosexual women are likely to differ in 2D:4D, even if multiple studies were missing from our data set (indicating no effect of publication bias). Specifically, 58 (right hand) and 43 (left hand) null effects would be needed to render the effect sizes comparing heterosexual and lesbian women statistically nonsignificant. Omit one study analyses produced Hedge's g values ranging from .21 to .32 (right hand) and .18 to .27 (left hand) for women, and from −.06 to .01 (right hand) and from −.07 to .01 (left hand) for men. All effect size estimates were statistically significant for women and nonsignificant for men, indicating that our results were robust and did not rely on the inclusion of any particular study.

The effect size heterogeneity across female, $Q(15) = 75.63$, $p < .001$, and male, $Q(17) = 48.35$, $p < .001$, samples suggested the presence of moderator variables. Below, we report results for moderator analyses separately for men and women.

2D:4D in Women: Categorical Moderator Analyses

Results of the six categorical moderator analyses (two hands by three categorical moderators) for women are shown in Table 2. One of six analyses found significant between-groups heterogeneity, indicating significant effect size differences between geographic locations: European samples were found to yield significantly larger effects ($g = .47$, $p < .001$) than North American samples ($g = .05$, *ns*). This result pertained to the left hand only; location did not moderate effect sizes for the right hand. Only one subgroup (North America) demonstrated within-group homogeneity; therefore, follow-up contrasts should be interpreted with caution.

The analysis examining moderation by method of digit measurement found no significant difference between effects from samples using direct measurement of digits and those that measured digits from photocopies, scans, or ink prints. The analysis examining moderation of effect sizes by exclusivity of preference also yielded no significant difference between effects from samples that compared exclusive heterosexual with exclusive gay persons and those studies that compared exclusive heterosexual with gay/bisexual persons.

2D:4D in Women: Continuous Moderator Analyses

We conducted weighted least squares regression analyses to examine whether age and ethnicity (percentage White) of sample were associated with the magnitude of effect sizes for women. Our results showed that neither age nor ethnicity was associated with the magnitude of effect sizes for the difference between 2D:4D in gay and heterosexual persons.

Table 2
Categorical Moderator Analyses for 2D:4D and Sexual Orientation in Women

Level of moderator	Q_b	k	Hedge's g	95% CI	Q_w
Geographic location (right hand)	1.56				
Europe		6	.46	[.11, .81]	22.63***
North America		10	.18	[−.09, .44]	33.29***
Geographic location (left hand)	6.91**				
Europe		6	.47	[.22, .71]	11.24*
North America		9	.05	[−.13, .24]	12.92
Exclusivity of preference (right hand)	0.38				
Exclusive		10	.33	[.02, .65]	56.99***
Nonexclusive		3	.14	[−.42, .69]	3.94
Exclusivity of preference (left hand)	1.53				
Exclusive		9	.35	[.08, .62]	35.84***
Nonexclusive		3	.01	[−.45, .47]	2.76
Digit measurement (right hand)	0.48				
Direct		4	.15	[−.31, .61]	7.69*
Photocopy/scan		12	.34	[.06, .63]	67.73***
Digit measurement (left hand)	0.11				
Direct		4	.19	[−.18, .56]	4.09
Photocopy/scan		11	.26	[.02, .50]	41.85***

* $p < .05$. ** $p < .01$. *** $p < .001$.

To examine effect size trends over time, we conducted a cumulative meta-analysis in which studies were sequentially pooled by adding one study at a time according to the date of publication (i.e., earliest to the most recent). With each new study added, cumulative effect sizes always indicated a more male-typical digit ratio for lesbians compared with heterosexual women (see online supplemental Figure S3). These effect sizes ranged from small to medium and pertained to the right hand. For the left hand, the first three studies in the cumulative meta-analysis showed no significant effect sizes; however, including subsequent studies yielded significantly positive, but small, effect sizes.

2D:4D in Men: Categorical Moderator Analyses

Results of the categorical moderator analyses for men are shown in Table 3. Again, results are presented for both right and left hands, giving a total of six analyses. The two analyses including geographic location yielded significant between-groups heterogeneity: For both hands, North American sample effect sizes were significantly different from European sample effect sizes. Samples from Europe had effect sizes that were in the positive direction ($g = .14$, *ns*, for right hand; $g = .17$, $p < .05$, for left hand), indicating that gay persons had lower (more masculine) mean digit ratios than heterosexual persons. North American samples had effect sizes that were in the negative direction ($g = -.17$, $p < .10$, for right hand; $g = -.23$, $p < .01$, for left-hand), indicating that gay persons had higher (more feminine) mean digit ratios than heterosexual persons. For the right hand, the North American subgroup showed within-group homogeneity, and for the left hand, the European subgroup showed within-group homogeneity. Given that there remained some within-subgroup variability in these analyses, results should be interpreted with caution.

The analysis examining moderation by method of digit measurement yielded no significant difference between effects from samples using direct measurement of digits and those that measured digits from photocopies, scans, or ink prints. In addition, the analysis examining moderation of effect sizes by exclusivity of preference found no significant difference between effects from samples that compared exclusively heterosexual with exclusively gay persons and those studies that compared exclusively heterosexual with gay/bisexual persons.

2D:4D in Men: Continuous Moderator Analyses

We conducted weighted least squares regression analyses to examine whether age and ethnicity (percentage White) of sample were associated with the magnitude of effect sizes for men.

The regression analysis examining the impact of ethnicity on effect sizes revealed a significant association between the percentage of White participants in a sample and the magnitude of the difference between 2D:4D in gay and heterosexual men, $Q_m(1) = 9.23$, $p < .01$, $R^2 = .33$ (right hand), and $Q_m(1) = 11.23$, $p < .001$, $R^2 = .44$ (left hand). In samples that predominantly comprised White participants, effect sizes indicated that gay men had a lower (more masculine) 2D:4D than heterosexual men. In samples that included fewer White participants, gay persons had a higher (more feminine) 2D:4D than heterosexual persons (see online supplemental Figure S4).

Thus, both geographical location and ethnicity moderated the relationship between 2D:4D and sexual orientation in men. These moderators were themselves correlated. Weighted for sample size, European samples had a significantly greater percentage of White participants than did North American samples, $F(1, 16) = 7.06$, $p = .019$. To explore whether geographical location or ethnicity might primarily drive the relationship between 2D:4D and sexual orientation, we conducted a mixed model ANOVA with geographical location as a between-subjects factor and ethnicity as a covariate, weighted by sample size. Ethnicity marginally significantly predicted the relationship between 2D:4D and sexual orientation in men, $F(1, 16) = 3.55$, $p = .082$, whereas geographical location did not, $F(1, 16) < 1$. Age was not associated with the

Table 3
Categorical Moderator Analyses for 2D:4D and Sexual Orientation in Men

Level of moderator	Q_b	k	Hedge's g	95% CI	Q_w
Geographic location (right hand)	5.98*				
Europe		9	.14	[−.04, .32]	19.96**
North America		8	−.17	[−.35, .01]	9.99
Geographic location (left hand)	11.16***				
Europe		9	.17	[.00, .34]	13.11
North America		7	−.23	[−.40, −.06]	11.83†
Exclusivity of preference (right hand)	0.29				
Exclusive		11	.02	[−.19, .22]	37.91***
Nonexclusive		4	−.09	[−.43, .25]	7.56†
Exclusivity of preference (left hand)	0.01				
Exclusive		10	−.01	[−.23, .22]	39.85**
Nonexclusive		4	−.03	[−.39, .33]	11.71**
Digit measurement (right hand)	0.32				
Direct		6	.04	[−.22, .30]	16.69**
Photocopy/scan		12	−.05	[−.23, .12]	29.78**
Digit measurement (left hand)	0.12				
Direct		6	.02	[−.25, .29]	11.06*
Photocopy/scan		11	−.02	[−.17, .14]	39.79***

$^{\dagger}p < .1$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

magnitude of effect sizes for the difference between 2D:4D in gay and heterosexual persons.

The cumulative meta-analysis revealed that, with each study's new appearance, effect sizes indicating the magnitude of the difference in 2D:4D between gay and heterosexual men were always nonsignificant. This result was consistent for the left and right hands.

Discussion

Since George (1930) demonstrated the sex difference in 2D:4D and Manning et al. (1998) pointed out its potential utility as a marker for prenatal sex hormones, numerous empirical studies have corroborated this normative sex difference. Our meta-analysis confirmed the sex difference in 2D:4D with a selected sample of heterosexual men and women who served as controls in at least some of the studies examining sexual orientation. We found that heterosexual men had significantly lower 2D:4D than did heterosexual women: This sex difference was highly robust, and its magnitude was greater for the right hand than for the left. Thus, right-hand 2D:4D is likely to more strongly reflect prenatal androgen exposure (Williams et al., 2000); hence, our discussion focuses on right-hand 2D:4D.

The primary finding of this study was that lesbians had a smaller, more masculine 2D:4D than did heterosexual women, whereas gay and heterosexual men did not differ significantly in 2D:4D. The right-hand 2D:4D difference between lesbian and heterosexual women was estimated to be small to medium in size. This difference was robust. A trim and fill analysis suggested the possibility of missing studies, and that the true effect size of the 2D:4D difference between heterosexual and lesbian women may be somewhat smaller than our estimate. Thus, some caution in interpretation is advisable. However, Rosenthal's fail-safe *N* indicated that 58 additional studies with null effects would be required to produce a statistically nonsignificant difference in 2D:4D between heterosexual and lesbian women. Furthermore, omit one study analysis indicated that this difference remained statistically significant regardless of which study was omitted; thus, the sexual orientation difference in 2D:4D in women did not rely on the inclusion of any particular study in our analysis.

Despite these robust findings, we found considerable heterogeneity in 2D:4D in both male and female samples, suggesting the presence of moderator variables. We therefore conducted moderator analyses, which examined possible effects of finger measurement method, method of sexual orientation assessment, age, geographic sampling location, and ethnicity on the relationship between 2D:4D and sexual orientation. We found no effects of finger measurement method, method of sexual orientation assessment, or age in either sex. Sampling location (Europe vs. North America) influenced the relationship between 2D:4D and sexual orientation in women only in the left hand and in both hands in men. Gay men had a lower 2D:4D in Europe and a higher 2D:4D in North America compared with heterosexual controls. Ethnicity also influenced the relationship between 2D:4D in men only and in both hands, such that higher proportions of White subjects were associated with a greater tendency for gay men to have a more masculine 2D:4D. Previous studies have reported effects of geographic location (McFadden et al., 2005) and ethnicity (Manning & Robinson, 2003; McFadden et al., 2005) on the relationship between 2D:4D and sexual orientation in men. We entered both variables into a single moderator analysis and found that geographic location did not explain a significant proportion of the variation in effect sizes beyond that explained by ethnicity. This suggests that the "effect" of geography observed in these samples is actually one of ethnicity.

Overall, our results support the hypothesis that prenatal androgen exposure affects sexual orientation in women. These results corroborate other evidence that androgen affects sexual orientation, such as sexual attraction to males in persons with CAIS (Hines et al., 2003; Money et al., 1984; Wisniewski et al., 2000) and sexual attraction to females in women with CAH (Hines et al., 2004; Money et al., 1984; Zucker et al., 1996) and prenatally normal males whose gender was reassigned near birth (Mustanski et al., 2002). Although these other lines of evidence cannot rule out the possibility that differential socialization, rather than altered prenatal androgen signaling, affected sexual orientation, 2D:4D appears to offer a means of doing so: People's finger length ratios are seldom known, and thus any relationships with sexual orientation are unlikely to be caused by socialization based on 2D:4D. Similarly, otoacoustic emissions (OAEs; sounds generated by the inner ear) may provide evidence of a relationship between androgen and sexual orientation that is not confounded by potential socialization effects. OAEs are thought to reflect early androgen exposure, and OAEs of lesbian and bisexual women are intermediate between those of heterosexual women and men (McFadden & Pasanen, 1998, 1999). Although it is logically possible that both 2D:4D and OAEs are correlated with other traits that affect social interactions and thereby alter psychosexual development, there is presently no evidence for this.

Our results also have implications regarding the timing of the development of sexual orientation. The relationship between 2D:4D and female sexual orientation suggests that these traits are not only dependent on the same developmental influences (e.g., circulating testosterone levels), but also that they are sensitive to these influences during the same time periods. In other words, the critical periods for the sexual differentiation of 2D:4D and sexual orientation probably overlap. As noted by Puts et al. (2008), sexual differentiation in 2D:4D likely begins between about 6 weeks of gestation, when testosterone production by Leydig cells begins (O'Shaughnessy, Baker, & Johnston, 2006), and 9 weeks of gestation, when substantial sexual differentiation in 2D:4D has already occurred (Galis et al., 2010; Malas et al., 2006). This implies that the critical period for the development of sexual orientation also probably begins during this interval and extends until sometime thereafter.

An important but unresolved question is why 2D:4D and sexual orientation were not related in a more straightforward way in men. One might imagine that if prenatal testosterone masculinizes both 2D:4D and sexual orientation in women, it would have similar effects in men. Several possible explanations for this incongruity exist.

First, sexual orientation is likely to be multifactorial and ontogenetically heterogeneous in both sexes. It is possible that gay men's sexuality is sufficiently diverse developmentally that, even if it sometimes results from sex-atypical prenatal androgen signaling, other developmental causes (e.g., maternal immune response due to fraternal birth order; Blanchard & Bogaert, 1996; Bogaert, 2006; Puts, Jordan, & Breedlove, 2006) may weaken a correlation with 2D:4D. In addition, our data suggest that gay men's sexuality may sometimes result from reduced androgenization and sometimes from elevated androgenization, and that ethnic (or genetic) background may determine which of these applies. If so, then in ethnically diverse populations, these negative and positive relationships between 2D:4D and male sexual orientation may effectively cancel each other, and the aggregate relationship may be negligible.

Alternatively, perturbations in prenatal androgen levels may generally have smaller effects on neurophysiological development in males than they do in females. Although prenatal testosterone levels have been found to correlate with childhood sex-typed behavior in both girls and boys (Auyeung et al., 2009), relationships between masculine childhood behavior and prenatal testosterone (or proxies of prenatal testosterone, such as CAH) are typically larger or observed only in girls (Hines, 2004; Hines, Golombok, Rust, Johnston, & Golding, 2002). Perhaps this is partly because androgen levels at the low end of the normal male range are sufficient to masculinize many aspects of the phenotype. If a relatively small androgen dose is required for the development of sexual attraction to females, then nearly all males may obtain sufficient androgen to promote attraction to females, and gay men's sexuality may result from something other than low androgen. Consequently, no relation to 2D:4D would be expected.

Finally, the possibility of different reporting biases across ethnicities should not be overlooked. For example, gay sexuality in men may be more stigmatized in some ethnic communities than in others (e.g., Pitt, 2006). This could lead to different rates of self-reported attraction to same-sex persons across ethnic groups and perhaps differences in the men who are classified or report themselves to be gay. For example, if only very feminine-acting gay men report a gay orientation in ethnic groups where this orientation is highly stigmatized, and if more feminine-acting gay men also have more a female-typical 2D:4D, then samples with higher proportions of ethnicities in which gay sexuality in men is highly stigmatized would show a greater tendency for gay men to have a higher, more feminine, 2D:4D.

The possibility of reporting biases is a limitation of all studies sampled in the present meta-analysis. On the one hand, it is unlikely that participants would misrepresent their sexual identity as gay or lesbian; on the other hand, it is possible that some study participants with gay/lesbian attractions reported, for reasons of social desirability, a heterosexual sexual identity (despite conditions of anonymity). This would, however, only have weakened the likelihood of detecting between-groups sexual orientation effects. Although it is likely that individuals who are open about their gay or lesbian sexual identity differ in various ways from their less open counterparts (e.g., degree of sexual liberalism vs. conservatism), it is unlikely that such a difference would be related to variations in 2D:4D.

A general limitation of meta-analyses of published studies is that nonsignificant findings may be less likely to get published, thus potentially biasing the meta-analyses. However, Rosenthal's fail-safe *N* indicated that a large number of nonsignificant unpublished studies would have to exist to cause the overall sex difference in 2D:4D, and the sexual orientation difference in 2D:4D in women, to become statistically nonsignificant. Given the modest number of studies analyzed and some evidence for publication bias, we encourage replication of these results as more data accumulate. We also encourage continued exploration of associations between digit ratio, sexual orientation, and moderator variables in men. In particular, future research should examine the potential effects of ethnicity on relationships between 2D:4D and sexual orientation, and consider possible subgroups of gay men (e.g., more typically masculine vs. more typically feminine gay men).

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