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Sexual Orientation and Handedness in Men and Women: A Meta-Analysis

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Recent findings suggest that sexual orientation has an early neurodevelopmental basis. Handedness, a behavioral marker of early neurodevelopment, has been associated with sexual orientation in some studies but not in others. The authors conducted a meta-analysis of 20 studies that compared the rates of non-right-handedness in 6,987 homosexual (6,182 men and 805 women) and 16,423 heterosexual (14,808 men and 1,615 women) participants. Homosexual participants had 39% greater odds of being non-right-handed. The corresponding values for homosexual men (20 contrasts) and women (9 contrasts) were 34% and 91%, respectively. The results support the notion that sexual orientation in some men and women has an early neurodevelopmental basis, but the factors responsible for the handedness–sexual orientation association require elucidation. The authors discuss 3 possibilities: cerebral laterality and prenatal exposure to sex hormones, maternal immunological reactions to the fetus, and developmental instability.

Over the past decade or so, there has been a resurgence of interest in identifying early neurodevelopmental determinants or correlates of sexual orientation, that is, a person's erotic preference for opposite-sex individuals (heterosexuality), same-sex individuals (homosexuality), or both (bisexuality). In part, this line of research has been stimulated by animal models of sexual orientation, in which it has been possible to experimentally manipulate potential causal or mediating variables, such as exposure to prenatal sex hormones (reviewed in Breedlove, 1994). In the study of human sexual orientation, the role of early neurodevelopment has been examined in several domains, including behavioral and molecular genetics, brain anatomy, dermatoglyphy, cerebral and auditory laterality, cognitive abilities, birth order, and childhood sex-typed behaviors. In this article, we briefly review the relevant findings in these domains and then argue that the study of handedness provides important and perhaps more direct information on the early neurodevelopmental basis of sexual orientation. We then present a meta-analysis of published and unpublished studies comparing the patterns of handedness of homosexual and heterosexual men and women.

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Behavioral and Molecular Genetics

There is evidence for the familiality of sexual orientation. For example, homosexual men appear to have more brothers who are also homosexual than do heterosexual men, and homosexual women appear to have more sisters who are also homosexual than do heterosexual women. Twin studies have provided evidence that part of this familiality is genetic, particularly for men (reviewed in Bailey & Pillard, 1995; Pillard & Bailey, 1998; see also Bailey, Dunne, & Martin, 2000).

One pedigree study found that the most discriminable pattern of genetic inheritance in homosexual men is X linkage (Hamer, Hu, Magnuson, Hu, & Pattatucci, 1993); however, a second pedigree study did not confirm this pattern of transmission (Bailey et al., 1999). Two molecular genetics studies (Hamer et al., 1993; Hu et al., 1995) localized the putative X-linked gene within the Xq28 region of the X chromosome, but a subsequent study did not replicate this finding (Rice, Anderson, Risch, & Ebers, 1999). No mode of Mendelian inheritance or chromosomal location has been found for women (Hu et al., 1995). The function of the putative genes underlying homosexuality in men remains to be clarified. One current hypothesis is that the genes, if they exist at all, affect the sexual differentiation of the fetal brain (see, e.g., LeVay & Hamer, 1994).

Brain Anatomy

Three postmortem studies have found differences between the brains of homosexual and heterosexual men. Swaab and Hofman (1990) found that the volume and density of the suprachiasmatic nucleus, which is not sexually dimorphic, were greater in homosexual men. LeVay (1991) found that the third interstitial nucleus of the anterior hypothalamus, which is smaller in women than in men (Allen, Hines, Shryne, & Gorski, 1989; Byne et al., 2000), was smaller in homosexual men. Allen and Gorski (1992) found that the midsagittal plane of the anterior commissure, which is larger in women than in men (Allen & Gorski, 1991), was larger in homosexual men. In a study using magnetic resonance scanning, Scamvouregas et al. (1994) found that the isthmus of the corpus callosum, which is larger in women than in men (Witelson, 1989), was larger in homosexual men. As yet, none of these studies has been replicated. Although is it likely that these differences were present before or during the development of sexual orientation, the methodology used does not completely rule out the possibility that these structural differences are the consequence of a person's sexual orientation (see Breedlove, 1997).

Dermatoglyphy

Dermatoglyphy refers to the study of finger, palmar, and plantar ridge counts and patterns (e.g., loops and whorls). J. A. Y. Hall and Kimura's (1994) study of dermal ridges pointed not only to an early origin of sexual orientation but also to a very specific temporal sequence. They found that the dermal ridges on fingertips, a physical feature that is fully developed by the 16th week of gestation and that does not change afterwards (Holt, 1968), showed more leftward asymmetry in homosexual men than in heterosexual men. Leftward asymmetry is a sexually dimorphic feature, being found more often in women (Kimura & Carson, 1993; but see Micle & Kobyliansky, 1988). Leftward asymmetry was also associated with left-handedness in homosexual men but not in heterosexual men. In a recent study, L. S. Hall (1998) reported that same-sex monozygotic twins concordant for sexual orientation showed concordant dermatoglyphic features, whereas same-sex monozygotic twins discordant for sexual orientation showed discordant dermatoglyphic features; these findings were observed in both sexes.

Cerebral and Auditory Laterality

Alexander and Sufka (1993) found that homosexual men showed different electroencephalographic activation during verbal and spatial tasks than heterosexual men and that their electroencephalographic patterns resembled those recorded from heterosexual women. Reite, Sheeder, Richardson, and Teale (1995) measured the magnetoencephalographic cerebral laterality of auditory source locations in homosexual and heterosexual men. They reported that women show less cerebral asymmetry than men on this measure and found that homosexual men showed less asymmetry than heterosexual men. Wegesin (1998b) did not find a difference between homosexual and heterosexual men in asymmetry of event-related potentials; however, he did find that homosexual men and women showed sex-atypical patterns of slow wave activity during a mental rotation task.

McFadden and Pasanen (1998) studied otoacoustic emissions (weak sounds produced by elements of the inner ear and evoked by brief sounds) in heterosexual men and women and homosexual or bisexual men and women. These emissions tend to be stronger in females and in the right ear; these sex and ear differences are observed among infants, children, and adults (McFadden, 1998). Results showed no difference between heterosexual and homosexual or bisexual men but weaker emissions among homosexual or bisexual women compared with heterosexual women. These findings may be relevant to early development because, McFadden and Pasanen suggested, on the basis of earlier findings from opposite-sex twins, comparison of men and women, and other evidence (reviewed in McFadden, 1998), that prenatal hormones may be responsible for the masculinization of otoacoustic emissions among homosexual or bisexual women.

Cognitive Abilities

Some studies have reported differences between heterosexual and homosexual men on sexually dimorphic measures of verbal and spatial abilities, with homosexual men scoring in the female-typical direction (see, e.g., McCormick & Witelson, 1991; Sanders & Wright, 1997; Wegesin, 1998a). However, others have failed to replicate these results (see, e.g., Gladue & Bailey, 1995). Studies comparing the cognitive performance of heterosexual and homosexual women have tended to find no difference (reviewed in Zucker & Bradley, 1995). There is evidence that prenatal hormones influence cognitive development (see, e.g., Grimshaw, Bryden, & Finegan, 1995; Hampson, Rovet, & Altmann, 1998; Resnick, Berenbaum, Gottesman, & Bouchard, 1986) and that contemporaneously measured hormonal levels influence cognitive performance (see, e.g., Janowsky, Chavez, Zamboni, & Orwoll, 1998).

Birth Order

Recent studies have shown that homosexual men tend to be born late in their sibships. More specifically, homosexual men tend to have a higher number of older brothers than do heterosexual men. The two groups do not differ with regard to other categories of siblings (reviewed in Blanchard, 1997; Jones & Blanchard, 1998). Two studies indicated that each older brother increases the odds of male homosexuality by 33% to 48% (Blanchard & Bogaert, 1996b; Blanchard, Zucker, Siegelman, Dickey, & Klassen, 1998). The older brother effect for homosexual men has been observed in a large number of diverse samples and is probably the most reliable finding in the literature on male homosexuality. Homosexual women do not differ from heterosexual women with regard to number of older brothers or any other category of siblings (Blanchard, 1997; Blanchard et al., 1998; Bogaert, 1997).

Blanchard and Klassen (1997) have argued that the most plausible explanation of the older brother effect involves an intrauterine mechanism. They proposed that a maternal immune response to male-specific fetal products could cause a disruption of fetal brain sexual differentiation and prevent the development of a male-typical sexual orientation. Because of the memory property of the immune system, each successive pregnancy of a male fetus would increase the likelihood and strength of an immune response. Although the actual antibodies remain to be identified, a plausible target of the immune response involves the male-specific, Y-linked, minor histocompatibility antigens.

It is, of course, also possible that postnatal mechanisms account for the older brother effect (for a review, see Blanchard, 1997). However, no postnatal theory has yet been proposed that can adequately explain the fact that number of older brothers is related to male homosexuality but number of older sisters is not related to male heterosexuality. Sulloway's (1996) theory of sibling differentiation suggests that later-borns' greater tendencies to be open to new experiences predispose them to engage in unconventional sex, including sex with same-sex partners and, as a result, increase the likelihood of developing a homosexual orientation. Sulloway's theory predicts, incorrectly, that homosexual men have a larger number of older siblings and a smaller number of younger siblings. Male-specific maternal immunoreactivity is currently the only theory that is consistent with the evidence and that specifies a plausible and testable mechanism (for a more complete description of this hypothesis as applied to male-biased neurodevelopmental characteristics, see Gualtieri & Hicks, 1985). This theory, however, is silent with regard to female homosexuality.

Childhood Sex-Typed Behaviors

Sex-typed behaviors refer to behaviors that, on average, are displayed more often by one sex than the other (e.g., rough-and-tumble play). Both prospective and retrospective studies have investigated whether variations in childhood sex-typed behaviors are associated with sexual orientation in adulthood. Prospective studies have examined samples of boys seen clinically because of extreme cross-sex-typed behaviors, and retrospective studies have examined both clinical and nonclinical samples of heterosexual and homosexual adults. Prospective studies have found that cross-sex-typed behaviors in boys strongly predict a homosexual sexual orientation in adulthood (Green, 1987; Zucker, 1985; Zucker & Bradley, 1995). On the basis of a meta-analytic review of the retrospective studies, Bailey and Zucker (1995) found that degree of childhood cross-sex-typed behaviors was significantly and strongly associated with a homosexual sexual orientation in both men (d = 1.31) and women (d = 0.96). For a subset of the retrospective studies, frequency distributions were available and pooled for a composite analysis, which showed that 89% of the homosexual men had a childhood sex-typed behavior score that exceeded the median score for heterosexual men (indicating more cross-sex-typed behaviors) and that 81% of the homosexual women had a score that exceeded the median score for heterosexual women. These results point to an early developmental genesis involving sexual differentiation.

The Importance of Handedness

The research reviewed so far indirectly suggests that sexual orientation has an early genesis involving neurodevelopment. Because of its early development, neurodevelopmental correlates, and sex-dimorphism, handedness can potentially provide more direct and more compelling information on the early neurodevelopmental basis of sexual orientation.

Early Development

Handedness appears quite early in development. Hepper, Shahidullah, and White (1991) observed, using ultrasound, that 92% of fetuses who sucked their thumbs tended to choose the right thumb, a value that is very close to the prevalence of right-handedness in the general population (89% of adults write and throw with their right hand; Gilbert & Wysocki, 1992). Hepper, McCartney, and Shannon (1998) reported that 10-week-old fetuses moved their right arm more often than their left, with 75% of fetuses showing a right arm bias. Goodwin and Michel (1981) studied head turning among neonates and hand preference among the same infants at 19 weeks of age: 63% of infants preferred to turn their head to the right, and 64% preferred the right hand in a reaching task (head turning tendencies and hand preference were significantly related). Gesell and Ames (1947) found that the tonic neck reflex observed in newborns strongly predicted handedness at ages 1, 5, and 10 years. Other researchers have observed sidedness in hand use (or other motor behaviors associated with handedness) among neonates and infants, especially among offspring of right-handed parents (see, e.g., Bates, O'Connell, Vaid, Sledge, & Oakes, 1986; Cioni & Pellegrinetti, 1982; Humphrey & Humphrey, 1987; Liederman & Kinsbourne, 1980), and have noted significant stability over time (see, e.g., Archer, Campbell, & Segalowitz, 1988).

Neurodevelopmental Correlates

Different patterns of handedness are associated with different patterns of cerebral laterality. In particular, most right-handers show leftward hemispheric laterality for language, and a majority shows a rightward hemispheric laterality for visuospatial abilities. Smaller percentages of left-handers show this laterality pattern (reviewed in Bryden & Steenhuis, 1991; Geschwind & Galaburda, 1987). Left-handedness is associated with a number of neurodevelopmental problems, including learning disabilities (e.g., dyslexia), mental retardation, autism, schizophrenia, cerebral palsy, and epilepsy (reviewed in Coren, 1993; Previc, 1996). Many of the neurodevelopmental problems associated with left-handedness are more prevalent in males (Gualtieri & Hicks, 1985).

Left-handedness is also associated with indicators of developmental instability (Yeo & Gangestad, 1998), such as fluctuating asymmetry of bilateral morphological traits (e.g., length of fingers) and minor physical anomalies (e.g., low-set ears). Fluctuating asymmetry can be produced by events occurring during pregnancy (Kieser & Groeneveld, 1994; Kieser, Groeneveld, & Da Silva, 1997; Livshits et al., 1988; Wilber, Newell-Morris, & Streissguth, 1993), is positively related to number of older brothers in men (Lalumière, Harris, & Rice, 1999), and is associated with neurodevelopmental dysfunctions (reviewed in Naugler & Ludman, 1996). Minor physical anomalies are formed early in pregnancy and indicate possible disturbances in brain development (see Bell & Waldrop, 1989).

Sex Difference

Boys are somewhat more likely to be left-handed than girls (Archer et al., 1988; Calnan & Richardson, 1976; Goodwin & Michel, 1981; Tan, Örs, Kürkçüolü, Kutlu, & Çankaya, 1992), and men are somewhat more likely to be left-handed than women (Gilbert & Wysocki, 1992; Oldfield, 1971; Perelle & Ehrman, 1994; Reiss & Reiss, 1997). The prevalence of left-handedness decreases more or less linearly with age in both sexes in cross-sectional studies (Coren & Halpern, 1991; Gilbert & Wysocki, 1992), reflecting either cohort effects or biased mortality rates associated with handedness.

Left-handedness has been found to be associated with homosexuality in some studies (e.g., Lindesay, 1987) but not in others (e.g., Bogaert & Blanchard, 1996). Narrative reviews of the relationship between handedness and sexual orientation have reached divergent conclusions (see, e.g., Halpern & Haviland, 1997; Zucker & Bradley, 1995). In this article, we present a quantitative review of published and unpublished studies on the relation between handedness and sexual orientation in men and women.

Method

Relevant studies were located by searching computerized reference databases and by examining reference lists of studies on handedness and sexual orientation. Unpublished data were solicited from researchers who had done work in the area of sexual orientation and from members of the closed electronic discussion list SEXNET (sexnet@listserv.acns.nwu.edu); the list membership includes a large number of clinical research sexologists. Data collection ended in January 1999.

Selection Criteria for Inclusion in the Meta-Analysis

Criterion 1: Participants. Studies had to include at least one sample of individuals likely to contain a majority of homosexuals—hereafter, the *target* sample. Potential target samples could be composed of self-declared homosexuals, middle-aged men who never married, men diagnosed with HIV and considered likely to be homosexual by the original authors, and women with a gender identity disorder. Samples of women who never married, men with a gender identity disorder, daughters of mothers exposed to diethylstilbestrol (DES) during pregnancy, and female patients with congenital adrenal hyperplasia (CAH) were not included in the meta-analysis but were examined separately, for reasons explained below.

Selected studies also had to include at least one sample of individuals likely to contain a majority of heterosexuals—hereafter, the *comparison* sample. Potential comparison samples could be composed of self-declared heterosexuals, adults who had married, and unselected groups of men or women. A variable indexing the manner in which sexual orientation was assessed was coded for further analyses (see below).

The use of marriage as a proxy for sexual orientation in men is justified by data from Blanchard and Bogaert (1997). Using a Bayesian analysis, Blanchard and Bogaert found that the probability that a never-married man over age 40 is homosexual is .70 to .85 (see also Kirk, Bailey, & Martin, 1999). Kirk et al.'s (1999) investigation of the sexual orientation of women over age 40 who have never married nor lived in a heterosexual relationship indicated that marriage (or its equivalent) is not a good proxy for sexual orientation among women.

The assumption that female-to-male, but not male-to-female, transsexuals are likely to be homosexual (i.e., to be sexually attracted to members of their own chromosomal sex) is justified by epidemiological data from Blanchard, Clemmensen, and Steiner (1987). In that study, a consecutive series of gender-dysphoric patients who presented at a university-affiliated gender identity clinic contained 73 heterosexual and 52 homosexual men and 1 heterosexual and 71 homosexual women. These findings indicate that biologically male gender-dysphoric patients are at least as likely to be heterosexual as homosexual, whereas female gender-dysphoric patients are overwhelmingly homosexual.

Compared with same-sex controls, women whose mothers were prescribed DES during their pregnancies and women with CAH report higher rates of bisexual fantasy and/or homosexual behavior (see, e.g., Dittmann, Kappes, & Kappes, 1992; Meyer-Bahlburg et al., 1995; Zucker et al., 1996). However, the majority of these women report an exclusively heterosexual sexual orientation, in both fantasy and behavior.

Criterion 2: Handedness. Studies had to use a well-specified measure of handedness that was the same for both the target and the comparison samples, and the handedness data had to be broken down by sex. Variables indexing the attributes of the handedness measures were coded for further analyses (see below).

Nineteen studies met both criteria. Another study (Satz et al., 1991) did not include a comparison sample, but we were able to use a comparison sample from the large Greater Cincinnati Survey (Lansky, Feinstein, & Peterson, 1988); this comparison sample is similar in sex, age, and ethnicity and was assessed with the same handedness questionnaire. The 20 studies provided 29 contrasts, 20 for men (Table 1) and 9 for women (Table 2). Eight of the nine studies reporting female data also reported male data. The data from Bailey, Willerman, and Parks (1991), Blanchard and Dickey (1998), Chivers (1995), and Tkachuk and Zucker (1991) are unpublished. Results from 14 studies that were considered but not included in the meta-analysis based on the two inclusion criteria are presented separately in the Results section.

Independence of the Samples and Total Sample Size

With 2 possible exceptions, the 29 target samples were independent, for a total of 6,182 male and 805 female participants. The possible exceptions are the studies by Becker et al. (1992) and Satz et al. (1991); both of these studies used data from the large Multicenter AIDS Cohort Study (MACS). However, we believe that the target samples reported in these 2 studies are independent because the authors did not cite each other and information contained in a description of the MACS (Kaslow et al., 1987) suggests that the participants in Becker et al. and Satz et al. were recruited at different sites.

Among studies reporting male data, four have partially overlapping comparison samples from the large Greater Cincinnati Survey (Lansky et al., 1988). For the Lansky et al. (1988) study, we used all 1,644 ever-married participants as a comparison sample (Table 5 in Lansky et al.). For Becker et al. (1992), we used 845 men as a comparison sample (Table 1 in Lansky et al.). For Götestam, Coates, and Ekstrand (1992), we used 380 young men as a comparison sample (Table 2 in Lansky et al.). For the Satz et al. (1991) study, we used 707 White men as a comparison sample (Table 2 in Lansky et al.).[1]

The studies by McCormick and her associates (McCormick, 1990; McCormick & Witelson, 1991; McCormick, Witelson, & Kingstone, 1990) provided one contrast for men and one for women. In the original studies, data from a group of 2,322 participants recruited by Annett (1970) were used to compare the rate of non-right-handedness of both male and female homosexual participants (approximately 73% of the comparison sample were men). We broke down Annett's sample into male (all male undergraduates plus all army recruits) and female (all female undergraduates) comparison samples using data described in Annett's Table 1. Thus, unlike the original reports by McCormick and her colleagues, the comparison samples used in the meta-analysis are independent and distinguished by sex.

Including Lansky et al. (1988) and excluding the other three studies using data from the same survey, the remaining 17 contrasts for men were based on 14,808 unique comparison participants. All female comparison samples were independent, providing 1,615 comparison participants. The total number of unique participants in this meta-analysis was 23,410.

Moderator Variables

Several variables were considered as potential moderators of the relationship between handedness and sexual orientation. A measure of the strictness of the determination of sexual orientation for the target participants was coded on a 3-point scale. A value of 1 was assigned when sexual orientation could be inferred only from other information (e.g., unmarried participants, female-to-male transsexuals); a value of 2 was assigned when sexual orientation was obtained from sexual behavior or interest informa-

[1] Thus, all male comparison participants in Götestam et al. (1992) and Satz et al. (1991) were also used by Becker et al. (1992), and all of these 845 male participants were included in Lansky et al. (1988); in the Lansky et al. study, however, approximately 80% of these 845 participants ended up in the comparison sample (this is the estimated proportion of men who had ever married in the overall sample), and the other 20% ended up in the target sample. Thus, the studies by Becker et al., Götestam et al., and Satz et al. are likely to have underestimated the group difference on handedness because some of the comparison participants were never married and thus likely to have been homosexual.

tion but was not strictly defined (e.g., from sexual behavior only; incomplete information on some participants; low, nonzero scores on the Kinsey scale of sexual orientation for some participants); a value of 3 was assigned when sexual orientation was strictly defined (e.g., self-declared or high scores on the Kinsey scale of sexual orientation). These values are presented in Tables 1 and 2, in the column labeled SO. Of the 29 contrasts, 21 had a strictness value of 3.

The column labeled Handedness shows the name of the handedness measure used (many studies used a smaller number of items from established handedness measures), the number of items used, and (when applicable) the range of scores that would classify a participant as exclusively left-handed, exclusively right-handed, or nonconsistently right-handed (NCRH); these ranges varied greatly across studies.

Six other moderator variables were examined: sex of participants, publication date, publication status, whether homosexual participants were recruited among HIV samples, rate of non-right-handedness among the target samples, and average age difference between the two groups. Age of participants is of particular concern because of the negative relationship between age and the proportion of left-handers in a given sample. Each of us independently coded the moderator variables for each study; the very few discrepancies were easily resolved.

Choice of Handedness Data

Some studies reported continuous handedness scores, and other studies reported categorical handedness classifications. All studies reported data that could be analyzed using a 2 × 2 contingency table. Thus, the categorical approach was chosen despite the fact that it is not statistically the most powerful way to detect a link between handedness and sexual orientation.

Each study provided data for at least one of the following contrasts: (a) exclusive left-handers versus all other participants, (b) exclusive left-handers versus exclusive right-handers (all mixed-handers excluded), (c) nonconsistent right-handers versus exclusive right-handers, and (d) participants who tended to favor the left hand versus participants who tended to favor the right hand. Because studies used different scoring criteria for any given type of contrast, the percentage of participants in a given category, such as left-handers, could not be averaged across studies.

The column labeled % Exclusive Left in Tables 1 and 2 shows, for each group, the percentage of participants who were classified as exclusive left-handers in each study (when possible). The column labeled % Left or NCRH shows, for each group, the percentage of participants who met the nonconsistent right-hander criterion or, when that information was not available, the percentage of participants who tended to favor the left hand rather than the right hand. In some instances, we had to determine the cutoffs ourselves from raw data (the details are presented in the tables).

Contrasts 3 and 4, which are fairly similar, were the most frequently reported; each study provided values for at least one of them. The data shown in the column labeled % Left or NCRH were thus used for the meta-analysis. It should be noted that the percentages are based on the same classification criterion within each study but on different criteria across studies. For the purpose of this meta-analysis, participants who were classified as nonconsistent right-handers or as favoring the left are called non-right-handers; all other participants (exclusive right-handers or those who favor the right, depending on the contrast) are called right-handers. Thus, this study is about non-right- versus right-handedness rather than left- versus right-handedness.

Meta-Analytic Strategy

Odds ratios. The main statistic for the meta-analysis was the odds ratio, calculated by dividing the ratio of non-right-handers to right-handers among the target participants by the similar ratio calculated for the comparison participants. A value larger than 1.0 indicates a larger proportion of non-right-handers in the target samples. Odds ratios are presented in parentheses in Tables 1 and 2. Values in boldface are significantly different from 1.0 at $p < .05$ (two-tailed).

The main advantage of this statistic is that it is independent of the base rate of non-right-handedness (as the base rate deviates from 50%, measures of association such as Pearson r get smaller even when the true effect size remains unchanged). In the context of the present meta-analysis, the base rate is affected by the handedness measure used or the cutoff criteria to determine non-right-handedness (e.g., the larger the number of items or the less stringent the criteria, the smaller the number of exclusive right-handers) and perhaps by the type of sample used (an older sample might include a smaller number of non-right-handers). Another advantage of odds ratios is that they provide an easily understandable measure of effect size. For example, a value of 2.0 means that a randomly chosen target participant is twice as likely to be non-right-handed as a randomly chosen comparison participant. We calculated the weighted average odds ratios and 95% confidence interval (CI) using the Mantel-Haenszel method, and a statistic of homogeneity of variance in observed odds ratios (Breslow and Day statistic) using the statistical package StatXact3 (Cytel Software Corporation). A primer on the meta-analysis of odds ratios can be found in Haddock, Rindskopf, and Shadish (1998).

Chi-square. Because the odds ratio approach is fairly new, we also used a more traditional meta-analytical strategy. We calculated a 2 × 2 contingency χ^2 value for each study based on the information summarized in Tables 1 and 2. The χ^2 value was then transformed into a standard deviate, $z = (\chi^2/N)^{.5}$. A positive sign was assigned to the z values when the proportion of non-right-handers was greater in the target sample and a negative sign when the proportion was greater in the comparison sample. The Stouffer procedure was used to determine the statistical significance of the average z value, $z = \Sigma z/K^{.5}$, where K refers to the total number of studies. We also calculated a nonparametric correlation, ϕ, which can be obtained from χ^2 (in a 2 × 2 table, ϕ is equivalent to Pearson's r).

Results

Among men, 17 of the 20 contrasts produced values indicating a higher frequency of non-right-handedness in the target sample than in the comparison sample (the probability of this finding by chance alone is about 1/1000). Among women, 7 of the 9 contrasts produced values indicating a higher frequency of non-right-handedness in the target sample (the probability of this finding by chance alone is about 1/14). In total, 24 of the 29 contrasts indicated a higher frequency of non-right-handedness in the target sample, but only 10 of those were statistically significant.

Meta-Analysis of Odds Ratios

Considering all 29 contrasts, the average odds ratio was 1.39, indicating that a randomly chosen target participant had 39% greater odds of being non-right-handed compared with a randomly chosen comparison participant. The 95% CI was 1.29 to 1.50, indicating that the average odds ratio was significantly different from 1.0. The 29 odds ratios were significantly heterogeneous, $\chi^2(28) = 75.72$, $p < .0001$, indicating that one or more variables influenced the relationship between handedness and sexual orientation.

Because of its theoretical importance, we first examined the moderating effect of sex. Contrasts involving female participants produced significantly larger odds ratios, $M = 1.91$ (95% CI 1.52 to 2.40) than contrasts involving male participants, $M = 1.34$ (95% CI 1.24 to 1.45) with no overlap between their CIs. The odds ratios

(*text continues on page 584*)

Table 1
Study Characteristics for Studies of Men

			Measures		% exclusive left		% left or NCRH		
Studies	Target group	Comparison group	SO	Handedness	Target (odds ratio)	Comparison	Target (odds ratio)	Comparison	Comments
Bailey, Willerman, & Parks (1991)	116 HOM	82 HET	3	10 items from Annett 10 to 29 = left 30 to 50 = right			18.1 (2.04)	9.8	Ps recruited from ads in various outlets. Handedness data were obtained from the first author. We calculated proportions from raw scores; 30 represented a break point in the distribution of the scores of all 294 ♂ and ♀ Ps (13.9% of the scores were below 30).
Becker et al. (1992)	1,612 HOM (age = 33.3)	845 ♂ (age ≈ 40)	2	5 items from Edinburgh 5 = left 5 to 24 = NCRH 25 = right	6.6 (**2.09**)	3.1	41.7 (1.17)	38.0	HOM Ps from MACS study on AIDS. 729 are HIV+. 92% White. Comparison Ps are from Lansky, Feinstein, & Peterson (1988, Table 1, left column). Not age (or otherwise) matched.
Bogaert & Blanchard (1996)	840 HOM (age = 29.2)	3,577 HET (age = 28.1)	3	1 item writing hand (left, ambi, right)	8.3 (1.18)	7.2	11.4 (1.05)	11.0	Kinsey Database. HOM older (*ns*), less educated (*ns*), equal parental SES. "Retrained to right" excluded ($n = 26$).
Blanchard & Dickey (1998)/Gebhard, Gagnon, Pomeroy, & Christenson (1965)	144 HOM (age = 32.2)	149 HET (age = 30.4)	2	1 item writing hand (left, ambi, right)	9.7 (1.68)	6.0	11.8 (1.11)	10.7	The handedness data were retrieved and analyzed at the Kinsey Institute (Bloomington, IN) according to instructions from the second author (Blanchard). HOM are men convicted of offenses against only men > 16 (mostly illegal sex with consenting men). HET are men convicted of offenses against only unrelated women > 16 (a wastebasket category of offenses not including rape, exhibitionism, or voyeurism). HOM older (*ns*) and better educated ($p < .001$).
Chivers (1995)	20 HOM (age = 25.3)	32 HET (age = 19.6)	3	23 items from Annett 23 to 96.5 = NCRH 96.6 to 115 = right			30.0 (0.43)	50.0	HOM older ($p < .001$) and better educated ($p < .001$).
Gladue & Bailey (1995)	72 HOM (age = 29.7)	76 HET (age = 27.9)	3	10 items from Annett −100 to +100 criteria unknown			22.2 (0.52)	35.5	Ps recruited from advertisements in "alternative" publications. HOM older ($p < .05$) and better educated (*ns*).
Götestam, Coates, & Ekstrand (1992)	394 HOM (age = 35.7)	380 ♂ (age = 18–39)	3	5 items from Edinburgh 1 = left 1 to 4 = NCRH 5 = right	6.9 (**2.26**)	3.2	56.6 (1.68)	43.7	Comparison Ps are White young men from Lansky et al. (1988).

Table 1 (*continued*)

			Measures		% exclusive left		% left or NCRH		
Studies	Target group	Comparison group	SO	Handedness	Target (odds ratio)	Comparison	Target (odds ratio)	Comparison	Comments
J. A. Y. Hall & Kimura (1995)	34 HOM	28 HET	3	8 items 2 to 8 = NCRH 0 to 1 = right			17.6 (2.79)	7.1	Ps recruited through ads and posters. HOM and HET matched for age and program of study.
Halpern & Cass (1994)	149 HIV+ (age = 37.0)	149 ♂ (age = 25.6)	2	4 items all right = right else = NCRH			30.9 (**1.77**)	20.1	135/149 HIV+ are self-declared homosexuals; 14 others of unknown sexual orientation; comparison Ps are friends and relatives of university students (% homosexuals unknown). HIV+ older ($p < .001$). All Ps completed high school.
Holtzen (1994, 1997)	85 HOM (age ≃ 30)	82 HET (age ≃ 55)	3	5 items from Edinburgh 1 = left 1 to 4 = NCRH 5 = right	11.8 (2.60)	4.9	36.5 (**2.34**)	19.5	HET are siblings and parents of the HOM. Twins, nongenetic relatives, and head-injured excluded. For all ♂ and ♀ studied (N = 401), mean age is 30.0 (HOM) and 54.9 (HET). Sexual orientation effect on handedness was obtained when age was controlled. HOM group included 10 bisexuals.
Lansky, Feinstein, & Peterson (1988)	439 never married	1,644 ever married	1	5 items from Edinburgh 1 = left 1 to 4 = NCRH 5 = right	3.0 (1.33)	2.3	41.6 (**1.93**)	26.9	Ps from a random probability survey. 48.5% of all Ps are 40+ years old (all are 18 and over).
Lindesay (1987)	94 HOM (age = 31.1)	100 HET (age = 28.6)	3	14 items from Annett −100 to −86 = left −100 to +85 = NCRH +86 to +100 = right	8.5 (2.33)	4.0	52.1 (**2.02**)	35.0	HOM are patients at a venereal clinic. Virgins and bisexuals excluded. HOM older (*ns*).
Marchant-Haycox, McManus, & Wilson (1991)	378 HOM	287 HET	3	9 items from McManus, Naylor, & Booker (1990) −100 to 0 = left 1 to +100 = right			11.6 (1.59)	7.7	Ps from venereal/AIDS clinics or members of gay clubs. 15.0% are HIV+. Mean age = 33.7 (all Ps).
McCormick (1990)/ McCormick, Witelson, & Kingstone (1990)/ McCormick & Witelson (1991)	56 HOM (age ≃ 26)	1,597 ♂ (age = young adults)	3	12 items from Annett all right = right else = NCRH			48.2 (**2.01**)	31.7	HOM recruited from homophile organizations. Comparison Ps from Annett (1970), Table 1. We used all identifiable men as comparison Ps.
Pattatucci, Patterson, Benjamin, & Hamer (1998)	273 HOM (age = 36.9)	246 HET (age = 35.7)	3	4 items all right = right else = NCRH			26.0 (**0.68**)	34.0	HOM recruited from homophile organizations and HIV clinics. HET are relatives. About 3 Ps per family. Same result when age, age^2, and education controlled.

(*table continues*)

Table 1 (*continued*)

Studies	Target group	Comparison group	Measures: SO	Measures: Handedness	% exclusive left: Target (odds ratio)	% exclusive left: Comparison	% left or NCRH: Target (odds ratio)	% left or NCRH: Comparison	Comments
Rosenstein & Bigler (1987)/Daniel & Yeo (1993)	22 non-HET	14 HET	2	10 items from Edinburgh median split at 11			59.1 (3.61)	28.6	Students. Non-HET: Kinsey > 0; HET: Kinsey = 0. Data presented are from Daniel & Yeo's (1993) reanalysis of proportions.
Satz et al. (1991)	993 HOM (age = 35.6)	707 ♂ (age ≃ 40)	3	5 items all right = right all left = left not all right = NCRH	6.3 (1.98)	3.1	42.5 (**1.32**)	35.9	HOM from MACS study on AIDS. 49.4% are HIV+. 90% White. We included a comparison sample from Lansky et al. (1988, White men in Table 2) tested with the same 5-item questionnaire and using the same classification criteria.
Stellman, Wynder, DeRose, & Muscat (1997)	420 never married	5,615 ever married	1	writing hand (left, right)			10.2 (1.36)	7.8	Hospital patients. 91.1% are ≥45 years old.
Tkachuk & Zucker (1991)	24 HOM (age = 31.0)	26 HET (age = 25.9)	3	22 items from Edinburgh −100 to −25 = left +26 to +100 = right			25.0 (2.56)	11.5	HOM are older ($p < .01$) and less educated (*ns*). Authors report a larger mean score (right shift) for HET group. We calculated proportions from raw scores; +26 represented a break point in the distribution of the scores of all 101 ♂ and ♀ Ps (14.9% of the scores were below +26).
Willmott (1975)/Willmott & Brierley (1984)	17 HOM (age = 22.9)	17 HET (age = 22.1)	3	3+ items 1 to 2 = left 1 to 3 = NCRH 4 to 5 = right	29.4 (1.35)	23.5	35.3 (1.77)	23.5	HOM are from nonclinical organized gay groups. HET from Round Table group. Data are taken from Willmott (1975). HOM have higher IQ (*ns*).

Note. P = participant; HOM = homosexual Ps; HET = heterosexual Ps; SO = sexual orientation: 1 = homosexual orientation is inferred (e.g., unmarried; female-to-male transexuals), 2 = homosexual orientation is obtained from sexual behavior/interest information but is not strictly defined (e.g., from sexual behavior only, incomplete information on some Ps; low but nonzero Kinsey score), 3 = homosexual orientation is strictly defined (e.g., self-declared, high Kinsey score); NCRH = nonconsistent right-handedness; MACS = Multicenter AIDS Cohort Study. Odds ratios in bold are statistically significant at $p < .05$.

Table 2
Study Characteristics for Studies of Women

Studies	Target group	Comparison group	Measures: SO	Measures: Handedness	% exclusive left: Target (odds ratio)	% exclusive left: Comparison	% left or NCRH: Target (odds ratio)	% left or NCRH: Comparison	Comments
Bailey, Willerman, & Parks (1991)	24 HOM	72 HET	3	10 items from Annett 10 to 29 = left 30 to 50 = right			12.5 (1.00)	12.5	Ps recruited from ads in various outlets. Handedness data were obtained from the first author. We calculated proportions from raw scores; 30 represented a breakpoint in the distribution of the scores of all 294 Ps (13.9% of the scores were below 30).
Gladue & Bailey (1995)	68 HOM (age = 29.5)	73 HET (age = 24.9)	3	10 items from Annett −100 to +100 criteria unknown			28.0 (0.96)	29.0	Ps recruited from advertisements. HOM older ($p < .001$) and better educated ($p < .05$).
J. A. Y. Hall & Kimura (1995)	12 HOM	20 HET	3	8 items 2 to 8 = NCRH 0 to 1 = right			25.0 (6.33)	5.0	Ps recruited through ads and posters. HOM and HET matched for age and program of study.
Herman-Jeglinska, Dulko, & Grabowska (1997)	85 TRAN	331 ♀	1	10 items from Edinburgh −100 to +40 = NCRH +41 to +100 = right			17.6 (**2.23**)	8.8	TRAN are female-to-male patients. Comparison Ps are students and faculty; matched on age and education.
Holtzen (1994, 1997)	56 HOM (age ≃ 30)	178 HET (age ≃ 55)	3	5 items from Edinburgh 1 = left 1 to 4 = NCRH 5 = right	7.1 (0.98)	7.3	39.3 (**2.16**)	23.0	HET are siblings and parents of the HOM. Twins, nongenetic relatives, and head-injured excluded. For all ♂ and ♀ studied (N = 401), mean age is 30.0 (HOM) and 54.9 (HET). Sexual orientation effect on handedness was obtained when age was controlled. HOM included 9 bisexuals.
McCormick (1990)/McCormick, Witelson, & Kingstone (1990)/McCormick & Witelson (1991)	45 HOM (age ≃ 26)	599 ♀ (age = young adults)	3	12 items from Annett all right = right else = NCRH			66.7 (**3.73**)	34.9	HOM recruited from homophile organizations. Comparison Ps from Annett (1970), Table 1. We used all identifiable women as comparison Ps.
Pattatucci, Patterson, Benjamin, & Hamer (1998)	478 HOM (age = 35.6)	276 HET (age = 45.0)	3	4 items all right = right else = NCRH			32.0 (**1.66**)	22.0	HOM recruited from homophile organizations and HIV clinics. HET are relatives. About 3 Ps per family. Same result when age, age^2, and education controlled.
Rosenstein & Bigler (1987)/Daniel & Yeo (1993)	16 non-HET	36 HET	2	10 items from Edinburgh median split (11)			81.3 (2.76)	61.1	Students. Non-HET: Kinsey > 0; HET: Kinsey = 0. Data presented are from Daniel & Yeo's (1993) reanalysis of proportions.
Tkachuk & Zucker (1991)	21 HOM (age = 28.3)	30 HET (age = 25.2)	3	22 items from Edinburgh −100 to −25 = left +26 to +100 = right			19.0 (3.29)	6.7	HOM are older ($p < .05$) and better educated (*ns*). Authors report a larger mean score (right shift) for HET group. We calculated proportions from raw scores. +26 represented a break point in the distribution of the scores of all 101 Ps (14.9% of the scores were below +26).

Note. P = participant; HOM = homosexual Ps; HET = heterosexual Ps; TRAN = transsexuals; SO = sexual orientation: 1 = homosexual orientation is inferred (e.g., unmarried; female-to-male transsexuals), 2 = homosexual orientation is obtained from sexual behavior/interest information but is not strictly defined (e.g., from sexual behavior only, incomplete information on some Ps; low but nonzero Kinsey score), 3 = homosexual orientation is strictly defined (e.g., self-declared, high Kinsey score); NCRH = nonconsistent right-handedness. Odds ratios in bold are statistically significant at $p < .05$.

were significantly different from 1.0 in both sexes and were heterogeneous for male contrasts, $\chi^2(19) = 55.78$, $p < .0001$, but not for female contrasts, $\chi^2(8) = 11.24$, *ns*.

We next examined the moderating effect of publication date. Figure 1 shows the distribution of the base 10 logarithms of the odds ratios as a function of the publication date (the base 10 logarithm transformation was used to normalize the distribution; a log odds ratio smaller than zero corresponds to an odds ratio of less than one); for unpublished studies, we used the date when the report was first available. Visual inspection shows that the effects tended to become smaller over time (the Pearson correlation between publication date for published studies and the log odds ratios was $-.317$, $p = .14$).

In an article that received a fair amount of scientific and media attention, McCormick, Witelson, and Kingstone (1990) suggested that nonconsistent right-handedness might be more prevalent among homosexuals than heterosexuals and that this result supported theories that postulate a neurobiological component to sexual orientation. It is possible that researchers (and editors) were more willing to publish null results after this publication. We calculated the weighted average odds ratio of studies published up to 1992 ($K = 10$), $M = 1.41$ (95% CI 1.27 to 1.57), and of studies published after 1992 ($K = 10$), $M = 1.18$ (95% CI 1.02 to 1.37). For this analysis, we included only published studies that explicitly focused on handedness and sexual orientation. Studies published after 1992 had significantly smaller odds ratios than studies published up to 1992, but both averages were significantly greater than 1.0. Unfortunately, there were not enough data points to perform this analysis within each sex. Because studies presenting both male and female data tended to produce similar results (the correlation between the log odds ratios within studies presenting both male and female data was .540), perhaps this finding holds for both sexes.

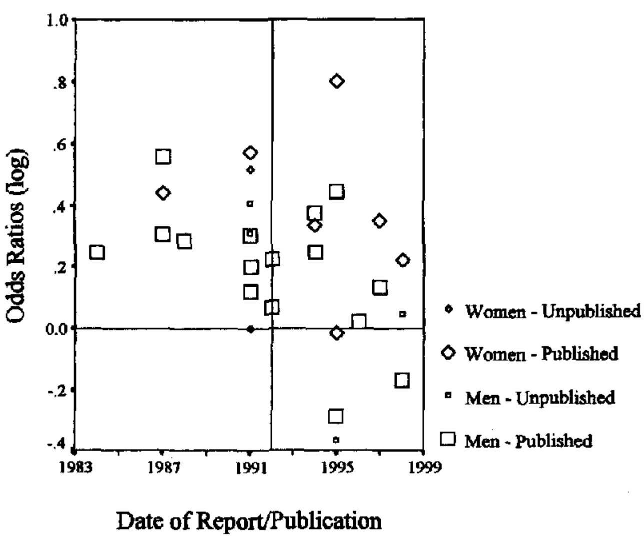

Figure 1. Distribution of log odds ratios as a function of publication date. Unpublished studies (smaller symbols) were assigned the date at which the data were first available. The area right of the vertical line represents the period after the publication of McCormick et al. (1990). Log odds ratios > 0 indicate greater prevalence of non-right-handedness among target samples.

We next examined the relationship between the log odds ratios and the other potential moderator variables. The log odds ratios were not affected by the strictness of the measure of sexual orientation, $F(2, 27) = 0.96$, *ns*. Using only data from the 21 contrasts that received a strictness rating of 3 (sexual orientation was self-declared or based on high scores on the Kinsey scale), we calculated the average odds ratio as 1.36 (95% CI 1.23 to 1.51).

The log odds ratios were not affected by the range of scores to determine non-right-handedness (range of 49% to 95% of the total score), $r(22) = -.015$, *ns*, the number of handedness items used (range of 1 to 23), $r(27) = .096$, *ns*, the use of multiple items as opposed to a single item, $t(27) = 1.18$, *ns*, publication status, $t(27) = 0.84$, *ns*, the rate of non-right-handedness among the target samples (range of 5.0% to 61.1%), $r(27) = -.299$, $p < .15$, or whether or not the target samples were recruited from HIV samples, $t(27) = -1.20$, *ns*. However, the log odds ratios were affected by the type of handedness measure used: The Edinburgh Inventory ($M = .36$) produced larger log odds ratios than the Annett questionnaire ($M = .10$) and the use of writing hand only ($M = .07$), overall $F(2,18) = 3.53$, $p < .06$.

Target participants were older than comparison participants in 12 of 17 contrasts with available data (mean age difference from -24.9 to 11.4 years). As expected from the handedness–age association literature, a larger age difference favoring the target participants was (nonsignificantly) associated with smaller log odds ratios, $r(15) = -.280$, $p < .30$. The mean odds ratio was 1.17 (95% CI 1.02 to 1.34) for the 12 contrasts in which target participants were older and 1.32 (95% CI 1.18 to 1.49) for the 5 contrasts in which comparison participants were older.

Meta-Analysis of Chi-Squares

The unweighted average ϕ obtained from the chi-squares was .096 (corresponding to a Cohen's d of 0.22).[2] The Stouffer z was 8.67, indicating an extremely low probability of a Type 1 error. The file-drawer problem statistic (Rosenthal, 1991) indicated that 539 studies with a null result would be needed to eliminate this statistically significant effect. The z values were heterogeneous, $\chi^2(29) = 106.15$, $p < .001$, indicating that they did not come from the same population of z values and that one or more study or sample characteristics were responsible for the observed variance in z. These results are quite consistent with the results obtained for odds ratios.

Studies Not Included in the Meta-Analysis

Other studies presented handedness data but did not meet our two selection criteria. Because other researchers might have used different criteria, we present the results of these studies here and calculated odds ratios when possible.

Studies of transsexuals. Watson (1991) presented sidedness data based on a 24-item inventory of hand, foot, eye, and ear preference used with 32 male-to-female transsexuals from the Vancouver General Hospital Gender Dysphoria Clinic and 160 controls "matched for age and genetic sex (male)" (p. 23). Using only handedness data, 40.6% of transsexuals and 11.9% of controls

[2] The weighted averages for ϕ and d were .053 and 0.151, respectively.

showed left-handedness, odds ratio = 5.08, $p < .0005$; the corresponding values for nonconsistent right-handedness were 71.9% and 25.6%, odds ratio = 7.42, $p < .0001$. Using a larger sample from the same clinic, Watson and Coren (1992) reported that 35.6% of the 45 male-to-female transsexuals and 11.6% of the 250 male controls (matched for age) showed left-handedness on a 4-item measure, odds ratio = 4.20, $p < .0005$. In this larger sample, 28% of the transsexuals described themselves as homosexual, 37% as heterosexual, 19% as bisexual, and 16% as asexual.

Herman-Jeglinska, Dulko, and Grabowska (1997) reported handedness data (10-item measure from the Edinburgh Inventory) from 15 male-to-female transsexuals and 148 male controls matched on age and education. Twenty percent of transsexuals and 12.8% of controls showed non-right-handedness, odds ratio = 1.70, $p < .50$. Orlebeke, Boomsma, Gooren, Verschoor, and van den Bree (1992) presented handedness data (6-item measure from the Edinburgh Inventory) from 93 male-to-female and 44 female-to-male Dutch transsexuals. Nineteen percent of the male-to-female and 18% of the female-to-male transsexuals showed left-handedness. These values were compared with the proportion of left-hand writing (11%) in the "age-matched part of the Dutch population" (p. 353). It is difficult to interpret these figures because a 6-item measure is more likely to yield non-right-handedness than a 1-item measure. Cohen-Kettenis, Van Goozen, Doorn, and Gooren (1998) reported that 28% of their female-to-male transsexuals and 7% of their male-to-female transsexuals were left-handed or ambidextrous using writing hand as a measure of handedness.

Studies of daughters of women exposed to DES.[3] Schachter (1994) assessed handedness using a 10-item Edinburgh Inventory in a sample of 77 women (mean age = 34) whose mothers had been exposed to DES during pregnancy. Controls were 514 female patients at a gynecologic clinic under age 60 (mean age = 31). Seventy-four percent of DES daughters showed non-right-handedness compared with 46% for the controls, odds ratio = 3.34, $p < .0001$. Scheirs and Vingerhoets (1995) studied 175 daughters (mean age = 30) of mothers exposed to DES and 219 control women (mean age = 29) using an 18-item measure of sidedness. On the composite measure of handedness, 28.6% of DES daughters and 19.2% of controls showed nonconsistent right-handedness, odds ratio = 1.69, $p < .05$. Using writing hand only, 17.1% of DES daughters and 9.6% of controls show left-handedness, odds ratio = 1.95, $p < .05$.

Studies of female patients with CAH. Nass et al. (1987) assessed handedness in a sample of 18 female patients with CAH (mean age = 12) and their sisters (mean age = 16) using the Edinburgh Inventory. The patients showed a statistically significant lower score (more left biased) on a laterality index. Helleday, Siwers, Ritzén, and Hugdahl (1994) assessed handedness in a sample of 22 women with CAH (mean age = 22) and 22 control women matched for age and place of birth using a 10-item Edinburgh inventory. Eighteen percent of CAH women were non-right-handed compared with 9% of the controls, odds ratio = 2.22, $p < .40$.

Other studies. Stellman, Wynder, DeRose, and Muscat (1997) studied the handedness of 201 women who had never married and 2,702 women who had been married at least once. Ninety-one percent of the total sample were women over the age of 45. Eight percent of the never-married and 6.8% of the ever-married wrote with their left hand, odds ratio = 1.18, $p < .55$. Wegesin, Sell, and Dean (1997) reported that 24.7% of their 741 homosexual men showed nonconsistent right-handedness using a 12-item measure of handedness (derived from the Edinburgh Inventory) but did not include a comparison group. J. A. Y. Hall and Kimura (1994) reported an incidence of adextrality of more than 16% among a sample of 66 homosexual participants using an 8-item measure of handedness. The homosexual participants could not be compared with the heterosexual participants because the latter were selected for handedness. Moose (1993) reported that 6.5% of homosexual participants (mean age = 28; 15 men and 16 women) and 16% of heterosexual participants (mean age = 34; 15 men and 17 women) were left-handed, odds ratios = 0.37, $p < .30$. The measure of handedness was not specified, and the data were not broken down according to sex. Finally, Reite et al. (1995) reported a mean handedness score of 0.87 for 9 homosexual men and 0.63 for 8 heterosexual men, $t(15) = -.72$, *ns* (our calculation). The handedness measure was "based on Annett (1970) with 1.0 = totally right handed" (p. 587).

Discussion

This meta-analysis of 29 contrasts involving 23,410 unique participants revealed a small reliable association between handedness and sexual orientation: Compared with heterosexual participants, homosexual participants had 39% greater odds of being non-right-handed.[4] Although most individual studies showed higher rates of non-right-handedness in homosexual versus heterosexual participants, the group differences were not always statistically significant, explaining why some narrative reviews incorrectly concluded that the studies produced inconsistent results.

A significant relationship between handedness and sexual orientation was obtained in both sexes but was stronger in women. The size of the relationship was not significantly affected by the strictness of the measure of sexual orientation, the range of scores used to determine non-right-handedness, the use of single versus multiple items to determine handedness, the rate of non-right-handedness among the target samples, publication status, the age difference between the target and comparison groups, or whether participants were recruited among HIV samples. More recent studies produced, on average, weaker but nevertheless reliable associations than less recent studies. The Edinburgh Inventory (Oldfield, 1971), which has been described as a more carefully

[3] Geschwind and Galaburda (1985b) reported "a markedly elevated rate" (p. 526) of non-right-handedness in 77 adults exposed to DES in utero but did not include any detail.

[4] An odds ratio of 3.0 is generally considered to represent a large effect (Haddock et al., 1998). For another representation of the size of the effect, it is possible to calculate the proportion of non-right-handers among homosexual versus heterosexual samples using the formula $P_{hs} = 1 / 1+[((1/P_{ht}) - 1)/OR]$. P_{hs} refers to the proportion of non-right-handed homosexuals; P_{ht} refers to the assumed proportion of non-right-handed heterosexuals (this value has to be assumed because the studies reported in Tables 1 and 2 used different classification criteria and produced very different estimates); OR refers to the average odds ratio reported in this meta-analysis (1.39). If 20% of heterosexuals are non-right-handed, then about 26% of homosexuals would be non-right-handed. We are grateful to James Cantor for expressing the relevant calculations in one equation.

developed questionnaire than the Annett questionnaire (Bryden, 1982, p. 162), produced the strongest associations.

The finding that the strictness of the measure of sexual orientation was unrelated to the size of the handedness–sexual orientation association deserves further comment. Eight studies were considered for inclusion in the meta-analysis but were excluded because the target samples did not contain a majority of homosexual participants. These samples comprised male-to-female transsexuals, daughters of women exposed to the masculinizing drug DES during pregnancy, female patients with the masculinizing condition CAH, and women who had never married. As explained in the Method section, these samples have somewhat higher but still minority proportions of homosexuals; nevertheless, there was an elevated prevalence of non-right-handedness in these groups.

There are two possible explanations for the findings obtained in these eight studies. First, it might be that the handedness–sexual orientation association is reliable enough to be detected even when the target (homosexual) sample does not contain a very high proportion of homosexuals. Second, non-right-handedness might be associated with other conditions in which sex-typical masculinization and feminization are disrupted, such as transsexualism, DES exposure, and CAH. Results from Casey and Nuttall (1990) indirectly speak to the second possibility. They found that non-right-handed women and right-handed women with non-right-handed relatives rated themselves as less feminine and had more masculine sex role identification than right-handed women with right-handed relatives.

Theoretical Implications

Handedness is observed quite early in development, has many neurodevelopmental correlates, and is minimally affected by psychosocial events (especially in the direction of developing non-right-handedness). Hence, the relationship between handedness and sexual orientation suggests that at least one developmental route to the development of homosexuality and heterosexuality involves factors affecting early neurodevelopment.

The findings that handedness and sexual orientation are associated in both men and women are difficult to explain with current etiological theories of homosexuality, especially the well-known hormonal theory of sexual orientation, which we here call the *prenatal androgen exposure theory*. The prenatal androgen exposure theory postulates that homosexuality in men is due to undermasculinization and, in women, to overmasculinization of the brain during a critical period of prenatal development (see Collaer & Hines, 1995; Dörner, 1972; Dörner, Rohde, Stahl, Krell, & Masius, 1975; Ellis & Ames, 1987). The main agents of masculinization in this theory are sex hormones, in particular, testosterone. With regard to sexual orientation, homosexual men have the gender preference of heterosexual women, and homosexual women have the gender preference of heterosexual men. The prenatal androgen exposure theory predicts that when homosexuals and heterosexuals differ on other characteristics, the difference will follow an overall pattern of undermasculinization among homosexual men and overmasculinization among homosexual women. For example, the overall advantage in verbal skills of heterosexual women over heterosexual men is predicted to be reduced or reversed in homosexual women.

The studies reviewed at the beginning of this article, as well as other findings (e.g., Blanchard & Bogaert, 1996a, on onset of puberty and body weight), strongly support the prediction of undermasculinization among homosexual men: When homosexual men differ from heterosexual men, they do so by showing less masculine (or clearly feminine) scores or characteristics. There are also some data suggesting that homosexual women sometimes differ from heterosexual women in a male-like direction (reviewed in Zucker & Bradley, 1995; see also Bogaert, 1998). Because non-right-handedness is somewhat more common in men than in women, one would expect from the prenatal androgen exposure theory that homosexual men would be less likely to be non-right-handed than their heterosexual counterparts and that homosexual women would be more likely to be non-right-handed than their heterosexual counterparts. The results of this meta-analysis show that non-right-handedness is more likely in homosexual than in heterosexual people of both sexes. Thus, with regard to the overall pattern of masculinization matching sexual orientation, the handedness data are consistent with the theory for women but not for men.[5]

Apart from James's (1989) theory relating sexual orientation, handedness, and testosterone (see below), a theory which has no direct empirical support, there is no prior theory that can explain why handedness and sexual orientation are related in both sexes and especially why non-right-handedness is elevated in homosexual men. In the following sections, we discuss three possible explanations for the relationship: cerebral laterality and prenatal exposure to sex hormones, maternal immunological reactions to the fetus, and developmental instability.

Cerebral laterality and prenatal exposure to sex hormones (revisited). Functional cerebral laterality refers to the differential processing of language and nonverbal (or spatial) abilities in the left and right hemispheres, respectively. An individual's preference for using the right or left hand has long been viewed as an indirect index of functional cerebral laterality (e.g., whether language is represented more strongly in the left or right hemisphere).

In their work on cerebral lateralization, Geschwind and Galaburda (1985a, 1985b) commented on the relationship between cerebral laterality, brain exposure to sex hormones, handedness, and sexual orientation. A central feature of Geschwind and Galaburda's model is that prenatal testosterone levels are related to the development of cerebral lateralization. More specifically, high levels of fetal testosterone during embryogenesis damage or slow the development of the normally dominant left hemisphere, allowing the right hemisphere to become equal or predominant and hence causing handedness and language lateralization to shift from the left hemisphere to bilaterality or the right hemisphere. Geschwind and Galaburda deduced that the sex difference in the fetal production of testosterone explains why men are more likely than women to be left-handed and also why men are more likely to suffer from learning disorders involving language.

[5] It should be kept in mind that the small sex difference in handedness may be simply due to the fact that more men than women are homosexuals (Laumann, Gagnon, Michael, & Michaels, 1994) and that more men than women are affected by conditions associated with handedness, such as autism and dyslexia (Gualtieri & Hicks, 1985). There might not be any sex difference in handedness among "unaffected" samples.

With women, the hypothesis regarding handedness and sexual orientation is straightforward: An overexposure to testosterone, as predicted by the prenatal androgen exposure theory, predisposes them to homosexuality and, as predicted by the Geschwind and Galaburda model, to non-right-handedness. Thus, the model for women correctly predicts a shift to a more male-typical pattern of increased non-right-handedness and sexual attraction to women.

With men, however, there have been two versions of the model's predictions. If homosexuality in men is due to an underexposure to testosterone, as predicted by the prenatal androgen exposure theory, then there should be a shift to a more female-typical pattern, that is, increased right-handedness and sexual attraction to men. However, Geschwind and Galaburda (1985a) modified this prediction on the basis of Ward and Weisz's (1980) study of stressed pregnant rats, in which male fetuses responded with an initial rise, then a permanent drop in testosterone, and more postnatal "homosexual" behavior (increased lordosis). Geschwind and Galaburda then referred to Dörner, Schenk, Schmiedel, and Ahrens's (1983) work on the putative greater prenatal stress experienced by the mothers of homosexual men than by the mothers of heterosexual men. Citing these observations, James (1989) surmised that "it seems reasonable to suggest that prenatal stress is associated with both high and low levels of [fetal] testosterone (at different stages of pregnancy) and thus . . . with both left-handedness and homosexuality in the same individual" (p. 179).

Although it is true that non-right-handedness is somewhat more common in men than in women, the evidence linking testosterone and handedness is largely indirect and sometimes contradictory. In a recent study, Grimshaw et al. (1995) found that prenatal levels of testosterone were associated with degree of cerebral lateralization in 10-year-old girls and boys; however, higher levels of testosterone were not associated with handedness in boys and were associated with right-handedness in girls. In addition, the relationship between prenatal stress and homosexuality in humans is far from certain (reviewed in Zucker & Bradley, 1995, pp. 155–160). Thus, current notions regarding hormonal mechanisms, sexual orientation, and cerebral laterality do not offer a cogent explanation of the relationship between non-right-handedness and homosexuality, particularly in men.

Maternal immunological reactions to the fetus. An alternative to the theory that the handedness–sexual orientation association is mediated by hormonal phenomena is the possibility that it is mediated by immunological phenomena, specifically, by the major histocompatibility complex (MHC). The MHC is a set of closely linked genes present in all vertebrate species. Molecules coded for by the MHC bind peptide antigens on cell surfaces, allowing them to be recognized by T cells. The two best studied MHCs are the murine MHC, H2, located on Chromosome 17, and the human MHC, human leukocyte antigens, located on Chromosome 6 (Benjamini & Leskowitz, 1991).

Gangestad et al. (1996) found a statistical association between left-handedness and specific MHC alleles. Their research was prompted by previously observed associations between left-handedness and autoimmune diseases on the one hand, and autoimmune diseases and particular MHC alleles on the other.

Blanchard et al. (1998) extended earlier theoretical work by Blanchard and Klassen (1997) with additional hypotheses that imply a statistical association between homosexuality and specific MHC alleles. Blanchard and Klassen had theorized that maternal antibodies to Y-linked minor histocompatibility antigens (HY antigens) might pass the placental barrier and divert the sexual differentiation of the fetal brain from the male-typical pattern. This notion—the maternal immunoreactivity hypothesis—was intended to account for the finding that homosexuality in men correlates with an individual's number of older brothers but not with his number of older sisters. The maternal immunoreactivity hypothesis is consistent with a variety of indirect evidence, reviewed by Blanchard and Klassen and by Blanchard (1997), including the probable involvement of HY antigens in the development of sex-typical traits in vertebrate species and the detrimental effects of immunization of female mice to HY antigens on the reproductive performance of subsequent male offspring.

Blanchard et al. (1998) noted that the maternal immunoreactivity hypothesis suggests a potential role for the MHC. In mice (Wachtel, Gasser, & Silvers, 1973) and rats (Desquenne-Clark, Chen, & Silvers, 1987), the ability of females to respond to HY antigens is determined by immune response genes situated in the MHC, and the ability of HY antigens to induce a response varies according to the MHC haplotypes of males. These findings raise the possibility of an association between MHC alleles and homosexuality in human males.

The foregoing suggests that the handedness–sexual orientation association could be mediated by the MHC. Perhaps there is some overlap between those MHC alleles that correlate with non-right-handedness and those that render HY antigens more visible (i.e., more antigenic) to the maternal immune system. Alternatively, perhaps there is some overlap between those MHC alleles that correlate with non-right-handedness and those that render HY antigens less visible to neighboring neurons in the fetal brain, thus diminishing a signal that contributes to the sexual differentiation of the brain in the male-typical pattern (see Ohno, 1977). Of course, this explanation of the handedness–sexual orientation association is speculative. There is, at present, no direct evidence that maternal antibodies to HY antigens contribute to homosexuality in human males, let alone evidence that the MHC background affects this process. In addition, these considerations are relevant only to male sexual orientation and do not address the handedness–sexual orientation association in women.

Developmental instability. The answer to the riddle will likely come from an accurate understanding of the meaning and origins of non-right-handedness and of unusual cerebral laterality. It is not the purpose of this article to review and evaluate the principal theories on this topic (see Previc, 1996; Yeo & Gangestad, 1993). Rather, we make use of recent concepts and findings from the very fertile research area of developmental instability to provide at least a partial answer to the riddle.

Developmental instability refers to an organism's degree of vulnerability to environmental and genetic stressors during development. As explained by Yeo and Gangestad (1998) and Møller and Swaddle (1997), all organisms experience at least a small amount of instability in development. Developmental instability can be caused by environmental factors such as pathogens, pollutants, and stress during pregnancy, and genetic factors such as spontaneous mutations and homozygosity. Thus, measures of developmental instability tell a historical tale about poor or disrupted design, random errors and accidents, or deleterious growing environments. Because many bilateral features (e.g., finger length) are controlled by the same genetic programs and are designed to develop symmetrically, asymmetry of bilateral features is often used as a measure of the extent to which organisms have experienced instability in development.

The importance of developmental instability is revealed by its associations with indicators of Darwinian fitness (e.g., disease resistance, growth rate, survival, and reproduction) in all species studied to date (reviewed in Møller, 1997; Møller & Swaddle, 1997; Thornhill & Møller, 1997). The measurement and sources of developmental instability have received a large amount of conceptual and empirical attention, especially among nonhuman species in which experimental manipulations are possible. Also, the concept of developmental instability forms the basis of many new studies on the effects of ecological changes on development and health, the effects of different selection pressures such as inbreeding, the relationship between genotypic quality and mate choice, and individual differences in neural organization (reviewed in Møller & Swaddle, 1997; Thornhill & Møller, 1997).

Yeo and Gangestad (1993, 1998; Gangestad & Yeo, 1994; Yeo, Gangestad, & Daniel, 1993) have pointed out that left-handedness is associated with indicators of reduced Darwinian fitness, including a smaller number of offspring, higher number of spontaneous abortions, lower birth weight, higher number of serious accidents, higher rates of serious disorders, and a shorter life span. Like others, they pointed out that left-handers are disproportionally represented among groups with neurodevelopmental disorders such as neural tube defects, autism, stuttering, and schizophrenia. Importantly, they have gathered evidence that deviation from moderate right-handedness (both left-handedness and extreme right-handedness) is associated in men and women with signs of developmental instability such as minor physical anomalies and fluctuating asymmetry of dermal ridges (both caused by prenatal events) and fluctuating asymmetry of other bilateral morphological traits (caused by prenatal or postnatal events).

Like non-right-handedness, signs of developmental instability such as fluctuating asymmetry and minor physical anomalies are associated with a number of neurodevelopmental problems (reviewed in Naugler & Ludman, 1996) and with atypical cerebral lateralization on neuropsychological tests in both sexes (Yeo, Gangestad, Thoma, Shaw, & Repa, 1997). Thus, the associations, in both sexes, among deviation from moderate right-handedness, fluctuating asymmetry, minor physical anomalies, atypical cerebral lateralization, and neurodevelopmental problems strongly suggest that deviation from moderate right-handedness is caused by perturbations occurring early in neurodevelopment. In other words, deviation from moderate right-handedness can be viewed as a sign of early instability in neurodevelopment in both men and women.

These notions and the result of this meta-analysis indicate that the factors diverting the development of erotic preferences away from the species-typical pattern of attraction toward opposite-sex adults are associated with instability in neurodevelopment. These notions are also consistent with the finding that the handedness–sexual orientation association is present in both sexes. If this logic is correct, one would expect that male and female homosexuality should be associated with other signs of developmental instability.[6]

No study has yet investigated the degree of fluctuating asymmetry or the presence of minor physical anomalies among homosexual men and women. However, it is worth noting that number of older brothers is associated with both male homosexuality (reviewed above) and male fluctuating asymmetry (Lalumière et al., 1999) in separate studies. We expect that deviation from moderate right-handedness might also be associated with number of older brothers in men but not in women; the methodology used in available studies on birth order and handedness (reviewed in Searleman, Porac, & Coren, 1989) does not allow a test of this hypothesis.

The fact that indicators of developmental instability are associated with both left-handedness and extreme right-handedness suggests that a meta-analysis of studies that examined deviations from moderate right-handedness in either direction—as opposed to shifts toward left-handedness alone—might arrive at a larger estimate of the handedness–sexual orientation association. Unfortunately, such studies are not currently available in the literature. Interestingly, and in support of our contention, Herman-Jeglinska et al. (1997) showed that right-handed transsexuals had a more extreme hand preference than right-handed controls.

Conclusions

The findings reported in this article support the view that sexual orientation has an early neurodevelopmental basis. The notion of developmental instability can explain why non-right-handedness is related to homosexuality in both men and women. It does not, however, identify the specific neurodevelopmental mechanisms underlying sexual orientation. Much remains to be learned about the etiology of sexual orientation. With regard to homosexuality, this meta-analysis points to an early neurodevelopmental basis involving disruptive events causing developmental instability. It is very likely that the disruptive events modify sexual differentiation of the brain, perhaps through hormonal or immunological mechanisms. Future studies are necessary to determine if homosexuality in men and women is associated with other signs of developmental instability.

[6] Michael Seto pointed out to us that the stronger association among women is consistent with the notion of a higher threshold for pathological outcomes among women. Women seem to be more resistant than men to a large number of developmental problems but show more serious effects when they are affected (see Gualtieri & Hicks, 1985). One might expect from these considerations that homosexual women would show more or stronger signs of developmental instability (other than non-right-handedness) than homosexual men.

References

References marked with an asterisk indicate studies included in the meta-analysis.

Alexander, J. E., & Sufka, K. J. (1993). Cerebral lateralization in homosexual males: A preliminary EEG investigation. *International Journal of Psychophysiology, 15,* 269–274.

Allen, L. S., & Gorski, R. A. (1991). Sexual dimorphism of the anterior commissure and massa intermedia of the human brain. *Journal of Comparative Neurology, 34,* 895–903.

Allen, L. S., & Gorski, R. A. (1992). Sexual orientation and the size of the anterior commissure in the human brain. *Proceedings of the National Academy of Sciences, USA, 89,* 7199–7202.

Allen, L. S., Hines, M., Shryne, J. E., & Gorski, R. A. (1989). Two sexually dimorphic cell groups in the human brain. *Journal of Neuroscience, 9,* 497–506.

*Annett, M. (1970). A classification of hand preference by association analysis. *British Journal of Psychology, 61,* 303–321.

Archer, L. A., Campbell, D., & Segalowitz, S. J. (1988). A prospective study of hand preference and language development in 18- to 30-month olds: I. Hand preference. *Developmental Neuropsychology, 4,* 85–92.

Bailey, J. M., Dunne, M. P., & Martin, N. G. (2000). Genetic and environmental influences on sexual orientation and its correlates in an Australian twin sample. *Journal of Personality and Social Psychology, 78,* 524–536.

Bailey, J. M., & Pillard, R. C. (1995). Genetics of human sexual orientation. *Annual Review of Sex Research, 6,* 126–150.

Bailey, J. M., Pillard, R. C., Dawood, K., Miller, M. B., Farrer, L. A., Trivedi, S., & Murphy, R. L. (1999). A family history study of male sexual orientation using three independent samples. *Behavior Genetics, 29,* 79–86.

*Bailey, J. M., Willerman, L., & Parks, C. (1991). A test of the maternal stress theory of human male homosexuality. *Archives of Sexual Behavior, 20,* 277–293.

Bailey, J. M., & Zucker, K. J. (1995). Childhood sex-typed behavior and sexual orientation: A conceptual analysis and quantitative review. *Developmental Psychology, 31,* 43–55.

Bates, E., O'Connell, B., Vaid, J., Sledge, P., & Oakes, L. (1986). Language and hand preference in early development. *Developmental Neuropsychology, 2,* 837–842.

*Becker, J. T., Bass, S. M., Dew, M. A., Kingsley, L., Selnes, O. A., & Sheridan, K. (1992). Hand preference, immune system disorder and cognitive function among gay/bisexual men: The Multicenter AIDS Cohort Study (MACS). *Neuropsychologia, 30,* 229–235.

Bell, R. Q., & Waldrop, M. F. (1989). Achievement and cognitive correlates of minor physical anomalies in early development. In M. H. Bornstein & N. A. Krasnegor (Eds.), *Stability and continuity in mental development* (pp. 63–85). Hillsdale, NJ: Erlbaum.

Benjamini, E., & Leskowitz, S. (1991). *Immunology: A short course* (2nd ed.). New York: WileyLiss.

Blanchard, R. (1997). Birth order and sibling sex ratio in homosexual versus heterosexual males and females. *Annual Review of Sex Research, 8,* 27–67.

Blanchard, R., & Bogaert, A. F. (1996a). Biodemographic comparisons of homosexual and heterosexual men in the Kinsey interview data. *Archives of Sexual Behavior, 25,* 551–579.

Blanchard, R., & Bogaert, A. F. (1996b). Homosexuality in men and number of older brothers. *American Journal of Psychiatry, 153,* 27–31.

Blanchard, R., & Bogaert, A. F. (1997). Additive effects of older brothers and homosexual brothers in the prediction of marriage and cohabitation. *Behavior Genetics, 27,* 45–54.

Blanchard, R., Clemmensen, L. H., & Steiner, B. W. (1987). Heterosexual and homosexual gender dysphoria. *Archives of Sexual Behavior, 16,* 139–152.

*Blanchard, R., & Dickey, R. (1998). Pubertal age in homosexual and heterosexual sexual offenders against children, pubescents, and adults. *Sexual Abuse, 10,* 273–282.

Blanchard, R., & Klassen, P. (1997). H-Y antigen and homosexuality in men. *Journal of Theoretical Biology, 185,* 373–378.

Blanchard, R., Zucker, K. J., Siegelman, M., Dickey, R., & Klassen, P. (1998). The relation of birth order to sexual orientation in men and women. *Journal of Biosocial Science, 30,* 511–519.

Bogaert, A. F. (1997). Birth order and sexual orientation in women. *Behavioral Neuroscience, 11,* 1395–1397.

Bogaert, A. F. (1998). Physical development and sexual orientation in women: Height, weight, and age of puberty comparisons. *Personality and Individual Differences, 24,* 115–121.

*Bogaert, A. F., & Blanchard, R. (1996). Handedness in homosexual and heterosexual men in the Kinsey interview data. *Archives of Sexual Behavior, 25,* 373–378.

Breedlove, S. M. (1994). Sexual differentiation of the human nervous system. *Annual Review of Psychology, 45,* 389–418.

Breedlove, S. M. (1997, October 23). Sex on the brain. *Nature, 389,* 801.

Bryden, M. P. (1982). *Laterality: Functional asymmetry in the intact brain.* New York: Academic Press.

Bryden, M. P., & Steenhuis, R. E. (1991). Issues in the assessment of handedness. In F. L. Kitterle (Ed.), *Cerebral laterality* (pp. 35–51). Hillsdale, NJ: Erlbaum.

Byne, W., Lasco, M. S., Kemether, E., Shinwari, A., Edgar, M. A., Morgello, S., Jones, L. B., & Tobet, S. (2000). The interstitial nuclei of the human anterior hypothalamus: An investigation of sexual variation in volume and cell size, number and density. *Brain Research, 856,* 254–258.

Calnan, M., & Richardson, K. (1976). Developmental correlates of handedness in a national sample of 11-year-olds. *Annals of Human Biology, 3,* 329–342.

Casey, M. B., & Nuttall, R. L. (1990). Differences in feminine and masculine characteristics in women as a function of handedness: Support for the Geschwind/Galaburda theory of brain organization. *Neuropsychologia, 28,* 749–754.

*Chivers, M. (1995). *Sexual orientation, handedness, and the effects of practice on a mental rotation task.* Unpublished B.A. honors thesis, University of Guelph, Guelph, Ontario, Canada.

Cioni, G., & Pellegrinetti, G. (1982). Lateralization of sensory and motor functions in human neonates. *Perceptual and Motor Skill, 54,* 1151–1158.

Cohen-Kettenis, P. T., Van Goozen, S. H. M., Doorn, C. D., & Gooren, L. J. G. (1998). Cognitive ability and cerebral lateralization in transsexuals. *Psychoneuroendocrinology, 23,* 631–641.

Collaer, M. L., & Hines, M. (1995). Human behavioral sex differences: A role for gonadal hormones during early development? *Psychological Bulletin, 118,* 55–107.

Coren, S. (1993). *The left-hander syndrome.* New York: Vintage.

Coren, S., & Halpern, D. F. (1991). Left-handedness: A marker for decreased survival fitness. *Psychological Bulletin, 109,* 90–106.

*Daniel, W. F., & Yeo, R. A. (1993). Handedness and sexual preference: A re-analysis of data presented by Rosenstein and Bigler. *Perceptual and Motor Skills, 76,* 544–546.

Desquenne-Clark, L., Chen, H. D., & Silvers, W. K. (1987). Influence of the major histocompatibility complex (MHC) on the response to and expression of H-Y in rats. *Developmental Genetics, 8,* 189–194.

Dittmann, R. W., Kappes, M. E., & Kappes, M. H. (1992). Sexual behavior in adolescent and adult females with congenital adrenal hyperplasia. *Psychoneuroendocrinology, 17,* 153–170.

Dörner, G. (1972). *Sexualhormonabhängige Gehirndiffernzierung und Sexualität* [Sex hormone dependent brain differentiation and sexuality]. New York: Springer-Verlag.

Dörner, G., Rohde, W., Stahl, F., Krell, L., & Masius, W.-G. (1975). A neuroendocrine predisposition for homosexuality in men. *Archives of Sexual Behavior, 4,* 1–8.

Dörner, G., Schenk, B., Schmiedel, B., & Ahrens, L. (1983). Stressful events in prenatal life of bi- and homosexual men. *Experimental and Clinical Endocrinology, 81,* 83–87.

Ellis, L., & Ames, M. A. (1987). Neurohormonal functioning and sexual orientation: A theory of homosexuality–heterosexuality. *Psychological Bulletin, 101,* 233–258.

Gangestad, S. W., & Yeo, R. A. (1994). Parental handedness and relative hand skill: A test of the developmental hypothesis. *Neuropsychology, 8,* 1–7.

Gangestad, S. W., Yeo, R. A., Shaw, P., Thoma, R., Daniel, W. F., & Korthank, A. (1996). Human leucocyte antigens and hand preference: Preliminary observations. *Neuropsychology, 10,* 1–6.

*Gebhard, P. H., Gagnon, J. H., Pomeroy, W. B., & Christenson, C. V. (1965). *Sex offenders: An analysis of types.* New York: Harper & Row.

Geschwind, N., & Galaburda, A. M. (1985a). Cerebral lateralization, biological mechanisms, associations, and pathology: I. A hypothesis and a program for research. *Archives of Neurology, 42,* 428–459.

Geschwind, N., & Galaburda, A. M. (1985b). Cerebral lateralization, biological mechanisms, associations, and pathology: II. A hypothesis and a program for research. *Archives of Neurology, 42,* 521–552.

Geschwind, N., & Galaburda, A. M. (1987). *Cerebral lateralization: Biological mechanisms, associations, and pathology.* Cambridge, MA: MIT Press.

Gesell, A., & Ames, L. B. (1947). The development of handedness. *Journal of Genetic Psychology, 70,* 155–175.

Gilbert, A. N., & Wysocki, C. J. (1992). Hand preference and age in the United States. *Neuropsychologia, 30,* 601–608.

*Gladue, B. A., & Bailey, J. M. (1995). Spatial ability, handedness, and human sexual orientation. *Psychoneuroendocrinology, 20,* 487–497.

Goodwin, R. S., & Michel, G. F. (1981). Head orientation position during birth and in infant neonatal period, and hand preference at nineteen weeks. *Child Development, 52,* 819–826.

*Götestam, K. O., Coates, T. J., & Ekstrand, M. (1992). Handedness, dyslexia and twinning in homosexual men. *International Journal of Neuroscience, 63,* 179–186.

Green, R. (1987). *The "sissy boy syndrome" and the development of homosexuality.* New Haven, CT: Yale University Press.

Grimshaw, G. M., Bryden, M. P., & Finegan, J. K. (1995). Relations between prenatal testosterone and cerebral lateralization in children. *Neuropsychology, 9,* 68–79.

Gualtieri, T., & Hicks, R. E. (1985). An immunoreactive theory of selective male affliction. *Behavioral and Brain Sciences, 8,* 427–441.

Haddock, C. K., Rindskopf, D., & Shadish, W. R. (1998). Using odds ratios as effect sizes for meta-analysis of dichotomous data: A primer on methods and issues. *Psychological Methods, 3,* 339–353.

Hall, J. A. Y., & Kimura, D. (1994). Dermatoglyphic asymmetry and sexual orientation in men. *Behavioral Neuroscience, 108,* 1203–1206.

*Hall, J. A. Y., & Kimura, D. (1995). Sexual orientation and performance on sexually dimorphic motor tasks. *Archives of Sexual Behavior, 24,* 395–407.

Hall, L. S. (1998). *Dermatoglyphic analysis of monozygotic twins discordant for sexual orientation (homosexuality, prenatal environment, maternal stress).* Unpublished doctoral dissertation, Temple University, Philadelphia.

*Halpern, D. F., & Cass, M. (1994). Laterality, sexual orientation, and immune system functioning: Is there a relationship? *International Journal of Neuroscience, 77,* 167–180.

Halpern, D. F., & Haviland, M. G. (1997). The correlates of left-handedness: Moderating variables in the epidemiology of left-handedness. *Annals of Epidemiology, 7,* 165–166.

Hamer, D. H., Hu, S., Magnuson, V. L., Hu, N., & Pattatucci, A. M. L. (1993, July 16). A linkage between DNA markers on the X chromosome and male sexual orientation. *Science, 261,* 321–327.

Hampson, E., Rovet, J. F., & Altmann, D. (1998). Spatial reasoning in children with congenital adrenal hyperplasia due to 21-hydroxylase deficiency. *Developmental Neuropsychology, 14,* 299–320.

Helleday, J., Siwers, B., Ritzén, E. M., & Hugdahl, K. (1994). Normal lateralization for handedness and ear advantage in a verbal dichotic task in women with congenital adrenal hyperplasia (CAH). *Neuropsychologia, 32,* 875–880.

Hepper, P. G., McCartney, G. R., & Shannon, E. A. (1998). Lateralised behaviour in first trimester human foetuses. *Neuropsychologia, 36,* 531–534.

Hepper, P. G., Shahidullah, S., & White, R. (1991). Handedness in the human fetus. *Neuropsychologia, 29,* 1107–1111.

*Herman-Jeglinska, A., Dulko, S., & Grabowska, A. M. (1997). Transsexuality and adextrality: Do they share a common origin? In L. Ellis & L. Ebertz (Eds.), *Sexual orientation: Toward biological understanding* (pp. 163–180). Westport, CT: Praeger.

Holt, S. B. (1968). *The genetics of dermal ridges.* Springfield, IL: Charles C Thomas.

*Holtzen, D. W. (1994). Handedness and sexual orientation. *Journal of Clinical and Experimental Neuropsychology, 16,* 702–712.

*Holtzen, D. W. (1997). Sexual orientation and handedness: A reanalysis of recent data and research considerations for future inquiry. In L. Ellis & L. Ebertz (Eds.), *Sexual orientation: Toward biological understanding* (pp. 151–161). Westport, CT: Praeger.

Hu, S., Pattatucci, M. L., Patterson, C., Li, L., Fulker, D. W., Cherny, S. S., Kruglyak, L., & Hamer, D. H. (1995). Linkage between sexual orientation and chromosome Xq28 in males but not in females. *Nature Genetics, 11,* 248–256.

Humphrey, D. E., & Humphrey, G. K. (1987). Sex differences in infant reaching. *Neuropsychologia, 25,* 971–975.

James, W. H. (1989). Foetal testosterone levels, homosexuality and handedness: A research proposal for jointly testing Geschwind's and Dorner's hypotheses. *Journal of Theoretical Biology, 136,* 177–180.

Janowsky, J. S., Chavez, B., Zamboni, B. D., & Orwoll, E. (1998). The cognitive neuropsychology of sex hormones in men and women. *Developmental Neuropsychology, 14,* 421–440.

Jones, M. B., & Blanchard, R. (1998). Birth order and male homosexuality: An extension of Slater's index. *Human Biology, 70,* 775–787.

Kaslow, R. A., Ostrow, D. G., Detels, R., Phair, J. P., Polk, B. F., & Rinaldo, C. R. (1987). The Multicenter AIDS Cohort Study: Rationale, organization, and selected characteristics of the participants. *American Journal of Epidemiology, 126,* 310–318.

Kieser, J. A., & Groeneveld, H. T. (1994). Effects of prenatal exposure to tobacco smoke on developmental stability in children. *Journal of Craniofacial Genetics and Developmental Biology, 14,* 43–47.

Kieser, J. A., Groeneveld, H. T., & Da Silva, P. C. F. (1997). Dental asymmetry, maternal obesity, and smoking. *American Journal of Physical Anthropology, 102,* 133–139.

Kimura, D., & Carson, M. W. (1993). Cognitive pattern and finger ridge asymmetry. *Society for Neuroscience Abstracts, 19,* 560.

Kirk, K. M., Bailey, J. M., & Martin, N. G. (1999). How accurate is the family history method for assessing siblings' sexual orientation? *Archives of Sexual Behavior, 28,* 129–138.

Lalumière, M. L., Harris, G. T., & Rice, M. E. (1999). Fluctuating asymmetry and birth order: A first look. *Proceedings of the Royal Society of London B, 266,* 2351–2354.

*Lansky, L. M., Feinstein, H., & Peterson, J. M. (1988). Demography of handedness in two samples of randomly selected adults. *Neuropsychologia, 26,* 465–477.

Laumann, E. O., Gagnon, J. H., Michael, R. T., & Michaels, S. (1994). *The social organization of sexuality: Sexual practices in the United States.* Chicago: University of Chicago Press.

LeVay, S. (1991, August 30). A difference in hypothalamic structure between heterosexual and homosexual men. *Science, 253,* 1034–1037.

LeVay, S., & Hamer, D. H. (1994, May). Evidence for a biological influence in male homosexuality. *Scientific American, 270,* 44–49.

Liederman, J., & Kinsbourne, M. (1980). Rightward motor bias in newborns depends upon parental right-handedness. *Neuropsychologia, 18,* 579–584.

*Lindesay, J. (1987). Laterality shift in homosexual men. *Neuropsychologia, 25,* 965–969.

Livshits, G., Davidi, L., Kobyliansky, E., Ben-Amitai, D., Levi, Y., & Merlob, P. (1988). Decreased developmental stability as assessed by fluctuating asymmetry of morphometric traits in preterm infants. *American Journal of Medical Genetics, 29,* 793–805.

*Marchant-Haycox, S. E., McManus, I. C., & Wilson, G. D. (1991).

Left-handedness, homosexuality, HIV infection and AIDS. *Cortex, 27,* 49–56.

*McCormick, C. (1990). *A neuropsychological study of sexual orientation: Neurobiological implications.* Unpublished doctoral dissertation, McMaster University, Hamilton, Ontario, Canada.

*McCormick, C. M., & Witelson, S. F. (1991). A cognitive profile of homosexual men compared to heterosexual men and women. *Psychoneuroendocrinology, 16,* 459–473.

*McCormick, C. M., Witelson, S. F., & Kingstone, E. (1990). Left-handedness in homosexual men and women: Neuroendocrine implications. *Psychoneuroendocrinology, 15,* 69–76.

McFadden, D. (1998). Sex differences in the auditory system. *Developmental Neuropsychology, 14,* 261–298.

McFadden, D., & Pasanen, E. G. (1998). Comparison of the auditory systems of heterosexuals and homosexuals: Click-evoked otoacoustic emissions. *Proceedings of the National Academy of Sciences, USA, 95,* 2709–2713.

McManus, I. C., Naylor, J., & Booker, B. L. (1990). Left-handedness and myasthenia gravis. *Neuropsychologia, 28,* 947–955.

Meyer-Bahlburg, H. F. L., Ehrhardt, A. A., Rosen, L. R., Gruen, R. S., Veridiano, N. P., Vann, P. H., & Neuwalder, H. F. (1995). Prenatal estrogens and the development of homosexual orientation. *Developmental Psychology, 31,* 12–21.

Micle, S., & Kobyliansky, E. (1988). Sex differences in the intraindividual diversity of finger dermatoglyphics: Pattern types and ridge counts. *Human Biology, 60,* 123–134.

Møller, A. P. (1997). Developmental stability and fitness: A review. *American Naturalist, 149,* 916–932.

Møller, A. P., & Swaddle, J. P. (1997). *Asymmetry, developmental stability, and evolution.* London: Oxford University Press.

Moose, B. J. (1993). *Spatial ability, sexual orientation, self-esteem, and sexual satisfaction measures in bisexuals, heterosexual and homosexuals.* Unpublished master's thesis, California State University, Stanislaus.

Nass, R., Baker, S., Speiser, P., Virdis, R., Balsamo, A., Cacciari, E., Loche, A., Dumic, M., & New, M. (1987). Hormones and handedness: Left-hand bias in female congenital adrenal hyperplasia patients. *Neurology, 37,* 711–715.

Naugler, C. T., & Ludman, M. D. (1996). Fluctuating asymmetry and disorders of developmental origins. *American Journal of Medical Genetics, 66,* 15–20.

Ohno, S. (1977). The original function of MHC antigens as the general plasma membrane anchorage site of organogenesis-directing proteins. *Immunological Review, 33,* 59–69.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9,* 97–113.

Orlebeke, J. F., Boomsma, D. I., Gooren, L. J. G., Verschoor, A. M., & van den Bree, M. J. M. (1992). Elevated sinistrality in transsexuals. *Neuropsychology, 6,* 351–355.

*Pattatucci, A. M. L., Patterson, C., Benjamin, J., & Hamer, D. H. (1998). A crossover interaction between sex, sexual orientation, and handedness. *Laterality, 3,* 331–342.

Perelle, I. B., & Ehrman, L. (1994). An international study of human handedness. *Behavior Genetics, 24,* 217–227.

Pillard, R. C., & Bailey, J. M. (1998). Human sexual orientation has a heritable component. *Human Biology, 70,* 347–365.

Previc, F. H. (1996). Nonright-handedness, central nervous system and related pathology, and its lateralization: A reformulation and synthesis. *Developmental Neuropsychology, 12,* 443–515.

Reiss, M., & Reiss, G. (1997). Lateral preferences in a German population. *Perceptual and Motor Skills, 85,* 569–574.

Reite, M., Sheeder, J., Richardson, D., & Teale, P. (1995). Cerebral laterality in homosexual males: Preliminary communication using magnetoencephalography. *Archives of Sexual Behavior, 24,* 585–593.

Resnick, S. M., Berenbaum, S. A., Gottesman, I. I., & Bouchard, T. J. (1986). Early hormonal influences on cognitive functioning in congenital adrenal hyperplasia. *Developmental Psychology, 22,* 191–198.

Rice, G., Anderson, C., Risch, N., & Ebers, G. (1999, April 23). Male homosexuality: Absence of linkage to microsatellite markers at Xq28. *Science, 284,* 665–667.

*Rosenstein, L. D., & Bigler, E. D. (1987). No relationship between handedness and sexual preference. *Psychological Reports, 60,* 704–706.

Rosenthal, R. (1991). *Meta-analytic procedure for the social sciences.* Newbury Park, CA: Sage.

Sanders, G., & Wright, M. (1997). Sexual orientation differences in cerebral asymmetry and in the performance of sexually dimorphic cognitive and motor tasks. *Archives of Sexual Behavior, 26,* 463–480.

*Satz, P., Miller, E. N., Selnes, O., Van Gorp, W., D'Elia, L. F., & Visscher, B. (1991). Hand preference in homosexual men. *Cortex, 27,* 295–306.

Scamvouregas, A., Witelson, S. F., Bronskill, M., Stanchev, P., Black, S., Cheung, G., Steiner, M., & Buck, B. (1994). Sexual orientation and anatomy of the corpus callosum. *Society for Neuroscience Abstracts, 20,* 1425.

Schachter, S. T. (1994). Handedness with women with intrauterine exposure to diethylstilbestrol. *Neuropsychologia, 32,* 619–623.

Scheirs, J. G. M., & Vingerhoets, A. J. J. M. (1995). Handedness and other laterality indices in women prenatally exposed to DES. *Journal of Clinical and Experimental Neuropsychology, 17,* 725–730.

Searleman, A., Porac, C., & Coren, S. (1989). Relationship between birth order, birth stress, and lateral preferences: A critical review. *Psychological Bulletin, 105,* 397–408.

*Stellman, S. D., Wynder, E. L., DeRose, D. J., & Muscat, J. E. (1997). The epidemiology of left-handedness in a hospital population. *Annals of Epidemiology, 7,* 167–171.

Sulloway, F. J. (1996). *Born to rebel.* New York: Pantheon Books.

Swaab, D. F., & Hofman, M. A. (1990). An enlarged suprachiasmatic nucleus in homosexual men. *Brain Research, 537,* 141–148.

Tan, U., Örs, R., Kürkçüoğlu, M., Kutlu, N., & Çankaya, A. (1992). Right-, left-dominance and ambidexterity in grasp reflex in human newborn: Importance of left brain in cerebral lateralization. *International Journal of Neuroscience, 62,* 197–205.

Thornhill, R., & Møller, A. P. (1997). Developmental stability, disease and medicine. *Biological Review, 72,* 497–548.

*Tkachuk, J., & Zucker, K. J. (1991, August). *The relation among sexual orientation, spatial ability, handedness, and recalled childhood gender identity in women and men.* Poster presented at the meeting of the International Academy of Sex Research, Barrie, Ontario, Canada.

Wachtel, S. S., Gasser, D. L., & Silvers, W. K. (1973, August 31). Male-specific antigen: Modification of potency by the H-2 locus in mice. *Science, 181,* 862–863.

Ward, I. L., & Weisz, J. (1980, January 18). Maternal stress alters plasma testosterone in fetal males. *Science, 207,* 328–329.

Watson, D. B. (1991). Laterality and handedness in adult transsexuals. *SIECCAN Journal, 6,* 22–26.

Watson, D. B., & Coren, S. (1992). Left-handedness in male-to-female transsexuals. *Journal of the American Medical Association, 267,* 1342.

Wegesin, D. J. (1998a). A neuropsychological profile of homosexual and heterosexual men. *Archives of Sexual Behavior, 27,* 91–108.

Wegesin, D. J. (1998b). Event-related potentials in homosexual and heterosexual men and women: Sex-dimorphic patterns in verbal asymmetries and mental rotation. *Brain and Cognition, 36,* 73–92.

Wegesin, D. J., Sell, R. L., & Dean, L. (1997, March). *Handedness and HIV status in gay men: Geschwind's theory revisited.* Paper presented at the Annual Meeting of the Cognitive Neuroscience Society, Boston.

Wilber, E., Newell-Morris, L., & Streissguth, A. P. (1993). Dermatoglyphic asymmetry in fetal alcohol syndrome. *Biology of the Neonate, 64,* 1–6.

*Willmott, M. (1975). *Cognitive characteristics and sexual orientation: Observations based on three highly selected groups.* Unpublished master's thesis, University of Newcastle upon Tyne, Newcastle upon Tyne, England.

*Willmott, M., & Brierley, H. (1984). Cognitive characteristics and homosexuality. *Archives of Sexual Behavior, 13,* 311–319.

Witelson, S. F. (1989). Hand and sex differences in the isthmus and genu of the human corpus callosum. *Brain, 112,* 799–835.

Yeo, R. A., & Gangestad, S. W. (1993). Developmental origins of variation in human hand preference. *Genetica, 89,* 281–296.

Yeo, R. A., & Gangestad, S. W. (1998). Developmental instability and phenotypic variation in neural organization. In N. Raz (Ed.), *The other side of the error term* (pp. 1–51). New York: Elsevier.

Yeo, R. A., Gangestad, S. W., & Daniel, W. F. (1993). Hand preference and developmental instability. *Psychobiology, 21,* 161–168.

Yeo, R. A., Gangestad, S. W., Thoma, R., Shaw, P., & Repa, K. (1997). Developmental instability and cerebral lateralization. *Neuropsychology, 11,* 552–561.

Zucker, K. J. (1985). Cross-gender-identified children. In B. W Steiner (Ed.), *Gender dysphoria: Development, research, management* (pp. 75–174). New York: Plenum.

Zucker, K. J., & Bradley, S. J. (1995). *Gender identity disorder and psychosexual problems in children and adolescents.* New York: Guilford Press.

Zucker, K. J., Bradley, S. J., Oliver, G., Blake, J., Fleming, S., & Hood, J. (1996). Psychosexual development of women with congenital adrenal hyperplasia. *Hormones and Behavior, 30,* 300–318.

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