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Human Handedness: A Meta-Analysis

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Across time and place, right hand preference has been the norm, but what is the precise prevalence of left- and right-handedness? Frequency of left-handedness has shaped and underpinned different fields of research, from cognitive neuroscience to human evolution, but reliable distributional estimates are still lacking. While hundreds of empirical studies have assessed handedness, a large-scale, comprehensive review of the prevalence of handedness and the factors that moderate it, is currently missing. Here, we report 5 meta-analyses on hand preference for different manual tasks and show that left-handedness prevalence lies between 9.3% (using the most stringent criterion of left-handedness) to 18.1% (using the most lenient criterion of nonright-handedness), with the best overall estimate being 10.6% (10.4% when excluding studies assessing elite athletes' handedness). Handedness variability depends on (a) study characteristics, namely year of publication and ways to measure and classify handedness, and (b) participant characteristics, namely sex and ancestry. Our analysis identifies the role of moderators that require taking into account in future studies on handedness and hemispheric asymmetries. We argue that the same evolutionary mechanisms should apply across geographical regions to maintain the roughly 1:10 ratio, while cultural factors, such as pressure against left-hand use, moderate the magnitude of the prevalence of left-handedness. Although handedness appears as a straightforward trait, there is no universal agreement on how to assess it. Therefore, we urge researchers to fully report study and participant characteristics as well as the detailed procedure by which handedness was assessed and make raw data publicly available.

Public Significance Statement

To date, this meta-analysis is the largest reported study to estimate the prevalence of left hand preference for different manual tasks across geographical areas (n = 2,396,170 individuals). It shows that the best estimate for the prevalence of left-handedness is 10.6%. However, this value varies between 9.3% and 18.1%, depending on how handedness is measured. The same evolutionary mechanisms should apply to participants of different geographical ancestries to maintain the roughly 1:10 ratio of left- versus right-handers found worldwide. The exact prevalence of left hand preference is moderated by cultural factors, primarily pressure to change writing hand, possibly because of direct instructions by parents and teachers and also through nonexplicit model learning. More data is needed

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for individuals with less represented ancestries. When 3 handedness categories are given (left-handed, mixed-handed, and right-handed), the best estimate for the prevalence of mixed-handedness is 9.33%, a number almost as large as the prevalence of left-handedness. This highlights the importance of taking this group into account in future handedness studies. Hand preference measurement moderates the estimated prevalences of left- and right-handedness. We urge researchers to define universal criteria for measuring hand preference (short questionnaires, reporting both writing hand and Edinburgh Handedness Inventory [EHI] scores, and reporting at least 2 classifications, e.g., R-L and R-M-L), as measurement imprecision and/or heterogeneity affects the estimated prevalence. Moreover, studies need to fully report study characteristics, such as instrument used to measure handedness (including questionnaire length and individual item content), response format, classification scheme, country in which the study took place, as well as population characteristics, such as sex, age, ancestry, and educational and sporting level of the participants, ideally by uploading raw data in open-access repositories. Detailed reporting is essential to compare effectively between different studies as well as to encourage good study design.

Keywords: handedness, meta-analysis, laterality, hand preference, cerebral asymmetries

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Laterality is a general principle of functional organization in vertebrates (e.g., Bisazza, Rogers, & Vallortigara, 1998; Güntürkün & Ocklenburg, 2017; Ocklenburg, Isparta, Peterburs, & Papadatou-Pastou, 2019; Rogers, 2008; Vallortigara & Rogers, 2005). *Homo sapiens* have evolved laterality in a unique form within our primate lineage (Uomini & Ruck, 2018). The population-level preferential use of the right hand has been the case at least since the days of *Homo habilis*, the precursor of modern *Homo sapiens*, two million years ago (Frayer et al., 2016; McManus, 2002). Recent estimations place the emergence of the right-hand bias in the course of the last seven million years (Uomini & Ruck, 2018).

Despite the fact that population-level right-hand preference is well established, the precise magnitude of the percentages of right- and left-handedness still remains to be elucidated. Handedness prevalence is indeed a point of dispute among different studies. Some of these differences might be explained by small sample sizes in individual studies, a problem that has been identified as one of the reasons for the current replication crisis in psychology. In addition to small sample sizes, inconsistent results are likely to be driven by publication bias, *p*-hacking, and heterogeneity in how handedness is measured. It has been suggested that one important methodological tool to avoid this problem and to identify true effects in psychological research are large-scale meta-analyses (Maxwell, Lau, & Howard, 2015). A large-scale, comprehensive review of the prevalence of handedness and its moderators is currently lacking, despite the wealth of studies investigating handedness.

Solving the riddle of the prevalence of handedness is not an easy task, because of the large number of published studies on handedness. For example, entering the key word "handedness" in PubMed in December 2019 resulted in 60,868 hits. A meta-analysis lends itself to producing an overview of all the primary studies using transparent methodology. By summarizing a research domain in such a quantitative manner, meta-analyses protect against overinterpreting differences across studies, while allowing for even small studies to contribute to the results of the overall analysis, thereby providing a safety net against wasting data. Meta-analyses further allow for moderators to be identified and small study bias to be detected. Small study bias may be caused by publication bias (also termed ascertainment bias), but could also be caused by other factors such as systematic differences in study quality between small and large studies. Large-scale, highly powered meta-analyses can help address the reproducibility issues that are at the forefront of scientific discussion within psychological research (e.g., Open Science Collaboration, 2015). Indeed, a number of publications have recently used meta-analysis to summarize the field of handedness (e.g., Markou, Ahtam, & Papadatou-Pastou, 2017; Ntolka & Papadatou-Pastou, 2018; see also Papadatou-Pastou, 2018).

Here we present five meta-analyses of studies that have measured hand preference to provide a reliable estimate of the prevalence of hand preference, disentangle the effects of the variables that are likely to moderate its magnitude, and to further estimate the possible presence of small study bias.

Why Handedness Matters

Understanding handedness and the prevalence of its different manifestations (i.e., left-, nonright-, mixed-, and right-handedness, as well as ambidexterity) can be very informative in a range of research fields, such as neuroscience, genetics, psychiatry, cognitive psychology, psychoneuroendocrinology, as well as evolutionary biology.

Handedness is a biological index—albeit indirect—of cerebral language lateralization. Knecht et al. (2000) in their seminal paper showed, using functional transcranial Doppler ultrasonography in a sample of 326 healthy participants, that the prevalence of right hemisphere language dominance increases linearly with the degree of left-handedness. More recent evidence reveals that most of the association between dominant hemispheres for language and hand use can be explained by the fact that strongly atypical individuals in terms of hemispheric lateralization are left-handers, although left-handedness can also found in participants with typical and ambilateral dominance (Mazoyer et al., 2014). Somers, Aukes, et al. (2015) further showed that degree of hand preference and degree of language lateralization fit a cubic regression model with stronger left-hand preference linked to a higher chance of atypical language lateralization.

Research on the genetics of handedness has recently made great strides forward. The heritability of handedness is estimated to be around 24% (Medland et al., 2009; Somers, Ophoff, et al., 2015). This is a relatively modest value suggesting that nongenetic factors may also contribute to handedness. Indeed, a recent analysis of the U.K. Biobank data showed a number of significant environmental influences on handedness, for example birth year, birth weight, being part of a multiple birth, and season of birth (de Kovel, Carrión-Castillo, & Francks, 2019). However, it has to be pointed out that while significant, these factors only had minimal predictive value for individual hand preference. Moreover, random measurement error could explain some of the variance.

In general, both genetic and nongenetic factors are being proposed for the emergence of human handedness (e.g., Güntürkün & Ocklenburg, 2017; Ocklenburg et al., 2017; Ratnu, Emami, & Bredy, 2017; Schaafsma, Riedstra, Pfannkuche, Bouma, & Groothuis, 2009; Schmitz, Kumsta, Moser, Güntürkün, & Ocklenburg, 2018; Schmitz, Metz, Güntürkün, & Ocklenburg, 2017; Sparrow et al., 2016). Individual factors are expected to contribute very small effects explaining why extremely large samples are required to identify genetic variants associated with handedness. McManus, Davison, and Armour (2013) estimated that at least 40 loci are involved in determining handedness, based on the ENGAGE meta-analysis of genome-wide association analysis (GWAS). More recently, GWAS in ~400,000 samples of the U.K. Biobank led to the identification of just a handful of significant associations (de Kovel & Francks, 2019; Wiberg et al., 2019). Different classifications did not impact on the overall results ((a) left-handers [n = 38,332] versus right-handers [n = 356,567]; (b) nonright handers [n = 44,631] versus right-handers [n = 356,567]; and (c) left-handers [n = 38,332] versus nonleft-handers [n = 362,866]). The most recent GWAS was conducted in an impressive sample of 1,534,836 right-handed, 194,198 (11.0%) left-handed, and 37,637 (2.1%) ambidextrous individuals and identified 48 variants reaching statistical significance (Cuellar Partida et al., 2019, preprint). The associations identified in these studies are enriched for genes that play a role in cellular pathways involved in neurodevelopment, such as neurogenesis, axonogenesis, and in microtubule organization. Similar pathways were also identified in a much smaller GWAS conducted for a relative hand skill measure (Brandler et al., 2013).

As it is the case for most genetic studies, sampling is biased toward an overrepresentation of samples with European ancestries. Genetic data from different populations might help to address the question of the effects of ethnicity in influencing left-handedness prevalence. Answering this question will require setting very specific criteria for assessing and defining handedness. Beyond the specific marker-trait associations, all the GWAS studies reported so far show an overlap between the genetic variation contributing to handedness and pathways implicated in neurodevelopmental and psychiatric disorders, such as schizophrenia and dyslexia. It has been suggested that this overlap might be mediated by biological factors involved in setting up left or right brain asymmetries (Brandler & Paracchini, 2014).

The links between handedness and psychiatric disorders have been investigated for decades well before these GWASs. A large body of literature has shown a higher prevalence of nonright-handedness in a number of psychiatric disorders, such as schizophrenia, as mentioned above (Deep-Soboslay et al., 2010; Dragovic & Hammond, 2005; Hirnstein & Hugdahl, 2014; Ravichandran, Shinn, Öngür, Perlis, & Cohen, 2017; Sommer, Aleman, Ramsey, Bouma, & Kahn, 2001; Tsuang, Chen, Kuo, & Hsiao, 2016), but also depression (Denny, 2009), bipolar disorder (Ravichandran et al., 2017; van Dyck, Pittman, & Blumberg, 2012), anxiety (Lyle, Chapman, & Hatton, 2013), neurotic disturbances (Milenković, Brkić, & Belojević, 2013), autism (Markou et al., 2017), alcoholism (Dömellof, Rönnqvist, Titran, Esseily, & Fagard, 2009), drug addiction (Preti et al., 2012), deafness (Papadatou-Pastou & Sáfár, 2016), intellectual disability (Papadatou-Pastou & Tomprou, 2015), and developmental disorders (Asenova, 2018). Therefore, having a robust estimate of the baseline of left-handedness could be also informative for this line of clinical handedness research.

Understanding handedness will also contribute to our understanding of human evolution. For example, it has been claimed that "right-handedness, along with the capacity to make and use tools, to use language, and to show functional and anatomical cerebral specialization, are characteristics specific to humans, and that they are intimately tied together in the divergent evolution of man from the apes" (McManus, 2019). Importantly, left-handers represent a substantial percentage of the human population (Willems, Van der Haegen, Fisher, & Francks, 2014). Therefore, when designing research studies, care should be taken so that left-handers are included in representative numbers. For example, evidence exists, albeit conflicting, that there are differences in the levels of testosterone between right- and left-handers (Moffat & Hampson, 1996; Papadatou-Pastou, Martin, & Mohr, 2017), and sample selection could be one of the factors resulting in these conflicting findings. Thus, if we are going to understand normal, but also pathological, functioning in terms of behavior, brain functioning, endocrinology, and genetics it is important to account for the variation within handedness (Willems et al., 2014).

Factors That Potentially Moderate Handedness Prevalence

Suggesting a genetic basis for handedness does not eliminate possible gene-environment interactions. Indeed, a number of environmental factors have been proposed and are likely to be moderating the reported prevalence of handedness both within and between populations. The most obvious example is cultural pressures, such as forcing left-handers to use their right hand for everyday activities like eating in some countries (e.g., De Agostini, Khamis, Ahui, & Dellatolas, 1997; Fagard & Dahmen, 2004; Shimizu & Endo, 1983) and most typically writing (e.g., Dellatolas et al., 1988; Siebner et al., 2002; Vuoksimaa, Koskenvuo, Rose, & Kaprio, 2009). Other environmental factors include nutrition; for instance, a large-scale review and meta-analysis showed that breastfeeding before the age of 9 months is associated with a decreased prevalence of nonright-handedness (Hujoel, 2019). There is also evidence that handedness may be influenced by season of birth (see Jones & Martin, 2008; Martin & Jones, 1999), with the proportion of births of left-handed people being higher within the spring and ensuing months (March–July in the northern hemisphere, September–January in the southern hemisphere) than within the other months.

Other factors that have been proposed to moderate the prevalences of left- and right-handedness can be largely grouped into (a) population characteristics and (b) study characteristics. Ancestry is one of the most studied population characteristics, with the prevalence of left-handedness found to be lower in Asia than in North America and Europe (Porac, Rees, & Buller, 1990). This is most likely to be because of differential cultural pressures against left-hand use, considering that only 3.5% and 0.7% of schoolchildren living in China (Teng, Lee, Yang, & Chang, 1976) and Taiwan (Hung, Tu, Chen, & Chen, 1985), respectively, were found to be left-handed, but 6.5% of schoolchildren of Asian descent living in the United States at around the same time were found to use their left hand for writing (Haryck, Goldman, & Petrinovich, 1975). Indeed, a low prevalence of left-handedness has been repeatedly found in societies with high levels of conformity (Brain, 1977; Jung & Jung, 2009; Komai & Fukuoka, 1934; Kushner, 2013; Lien, Chen, Hsiao, & Tsuang, 2015; Shimizu & Endo, 1983; Suar, Mandal, Misra, & Suman, 2013; Tsuang et al., 2016; Xu & Zheng, 2017; Zverev, 2006). For example, Lien et al. (2015) measured handedness in a sample of 640 college students in Taiwan and their 1,328 first-degree relatives and only 2.89% of these participants reported to write with their left hand. Jung and Jung's study (Jung & Jung, 2009) detected only 141 left-handers (5.8%) among 2,437 randomly selected Koreans. In Suar's et al. (2013) study, only 3.98% in a total of 3,698 participants in Kharagpur, India, wrote with their left hand. Zverev (2006) recorded self-reported hand preference in a sample of 440 participants (141 pupils, 68 teachers, and 231 guardians) derived from a secondary school in Malawi, Central Africa, and only 4.3% and 4.7% of the sample self-reported to be left-handed or mixed-handed, respectively. Family data show that the effect of cultural pressure on handedness can be differentiated from genetic effects (McManus, 2009).

Age has also been suggested to moderate the prevalence of handedness, with evidence of a decrease in left-handedness with increasing age in cross-sectional studies (e.g., de Kovel et al., 2019; Jung & Jung, 2009; Milenković et al., 2013; Preti et al., 2011). For example, Lee-Feldstein and Harburg (1982) have found that the proportion of left-handers is nearly twice as high for people under 40 years of age than for people that are over the age of 40 (14.8% vs. 8.4% for men and 13.4% vs. 7% for women). Kalisch, Wilimzig, Kleibel, Tegenthoff, and Dinse (2006) investigated hand motor performance in 20 to 90 year-old participants and found that the clear right-hand advantage seen in younger participants changed to a more balanced performance in older cohorts. Yet, older participants still self-identified as right-handers. These effects, however, do not indicate that handedness changes when people grow older. Rather this seems to be a generational effect, for example changes in social norms toward left-handedness over the decades affect the prevalence of left-handedness (Dellatolas et al., 1991; Hugdahl, Satz, Mitrushina, & Miller, 1993).

A higher percentage of left-handers has been found among the high achievers in sporting populations (Grouios, Tsorbatzoudis, Alexandris, & Barkoukis, 2000; Holtzen, 2000; Loffing, 2017; Loffing & Hagemann, 2012; Raymond, Pontier, Dufour, & Møller, 1996). According to Casey (1996) such advantages are neuroanatomically based and facilitate left-handed people in performing certain neurocognitive tasks, such as visuospatial and whole body tasks. The left hand and right hemisphere respond faster than the right hand and left hemisphere; thus, it may be the case that the left hand is preferred in some sports, even by people otherwise right-handed (Carson, Chua, Elliott, & Goodman, 1990). Wood and Aggleton (1989) support the hypothesis that any excess of left-handers in certain sports is simply because of the nature of the game. Left-handers merely have a tactical advantage, as they have more practice against right-handed opponents than right-handers have against left-handers. More recently, Loffing (2017) suggested that the left-handers' advantage is linked to the underlying time pressure of some interactive sports, such as table tennis and cricket.

Other population characteristics linked to handedness are homosexuality (Blanchard & Lippa, 2007; Lalumière, Blanchard, & Zucker, 2000; Xu & Zheng, 2017; Yule, Brotto, & Gorzalka, 2014), being a twin (Medland et al., 2009; Sicotte, Woods, & Mazziotta, 1999; Suzuki & Ando, 2014; Vuoksimaa et al., 2009, but see Zheng et al., 2019, preprint), being a triplet (Heikkilä et al., 2018) as well as education (Elneel, Carter, Tang, & Cuschieri, 2008; Faurie et al., 2008; Gupta, Sanyal, & Babbar, 2008; Kuderer & Kirchengast, 2016; Lyle et al., 2013; Noroozian, Lotfi, Gassemzadeh, Emami, & Mehrabi, 2002).

The key study characteristic influencing handedness is assessment, shown to contribute to frequency variation by introducing measurement artifacts (see Bishop, 1990). Assessment methods mainly include hand preference inventories and proficiency measures, assessing hand preference for everyday activities and relative hand skill, respectively. Hand preference measures are the most widely used instruments, both in experimental and clinical settings, as they are easier and more convenient to use than relative hand skill measures (Borod, Caron, & Koff, 1984). However, even among the different hand preference inventories one can find differences in patterns of distributions of the prevalence of right- and left-handedness (Holder, 1992). Provins, Milner, and Kerr (1982), for example, have reported collecting different percentages for different inventories resulting in even reclassifying some left-handers as clear right-handers. Self-classification consists of merely asking participants "Are you right- or left-handed" (Faurie et al., 2008). However, using a sample balanced for handedness and sex, Papadatou-Pastou, Martin, and Munafò (2013) found that self-classification matched writing hand in every case, while that the mismatch between self-classification and hand preference inventories was 0.4% for right-handers, but 13.5% for left-handers.

The apparent prevalence of handedness may also vary by virtue of questionnaire length (Holder, 1992; Peters, 1992). This can vary from the use of a single item such as writing hand (e.g., Silva & Satz, 1979) to the utilization of 75 items (e.g., Provins et al., 1982). Still, when the number of items is kept constant, then the content of the questionnaire, that is the nature of the items used, could affect the distribution of the results (Bryden, 1977; Gureje, 1988). Further, the type of response allowed is important. Papadatou-Pastou et al. (2013) found that an "either hand" response in a 5-point scale is more likely to be translated into a "right hand" response when the same item is presented with a forced choice ("right" vs. "left") response option, especially for right-handers. Furthermore, left-handers give more extreme nondominant hand responses that right-handers in 5-point scales and right-handers choose fewer either responses.

The handedness classification scheme used by each researcher also has a substantial impact on the number of individuals allocated to each group. Handedness may be classified into either discrete categories (e.g., Chisnall, 2010; Dinsdale, Reddon, & Hurd, 2011; Hannula, Bloigu, Majamaa, Sorri, & Mäki-Torkko, 2012) or by considering handedness a continuous variable (e.g., Dane et al., 2009). In the first case, the categories are usually right and left, with writing hand being the most common criterion for group assignment. One important factor to consider is whether there is a "middle category" between left- and right-handedness and how it is defined. Ambidexterity and mixed-handedness are the most commonly used terms for this middle category, although ambidexterity (being equally skilled with both hands for fine motor tasks) can be differentiated from mixed-handedness (preferentially using different hands for different tasks). However, the terms are often used interchangeably creating confusion. The allocation of individuals into different handedness categories depends on classification schemes with varying cut-offs. For example, in the Edinburgh Handedness Inventory (EHI; Oldfield, 1971), the most commonly used handedness questionnaire, participants answer 10 items about their preferred hand for everyday activities. Based on the number of left- and right-sided preferences as well as no preference for either hand, a so-called LQ (laterality quotient) is calculated. The LQ has a value between −100 (consistent left-handedness) and 100 (consistent right-handedness) and, based on their scores, individuals are categorized as having a specific hand preference. Unfortunately, these cut-off schemes often vary widely between different studies. For example, Fagard, Chapelain, and Bonnet (2015) categorized their participants into strong left-handers (LQ between −100 and −90), mixed left-handers (LQ between −90 and −30), ambidexter (LQ between −30 and 30), mixed right-handers (LQ between 30 and 90) and strong right-handers (LQ between 90 and 100) based on their responses in a self-developed questionnaire. In contrast, Arning et al. (2015) grouped their participants into right-handers (LQ between 40 and 100), left-handers (LQ between −100 and −40) and mixed handers (LQ between −40 and 40). These are only two examples of the many different classification schemes used that highlight the importance to come to a general consensus on how to use these terms to ensure comparability between different studies.

Scope of the Present Study

Here we report five large-scale meta-analyses, which integrate research findings from the broad field of handedness, to produce a reliable estimate of the prevalence of handedness categories, namely left-, nonright-, and mixed-handedness versus right-handedness. We further investigate the effect of factors that have been suggested to moderate the prevalence of handedness. In particular, we examine (a) population characteristics, such as location of testing (as a proxy of the participants' ancestry), educational level, and belonging to a sporting elite and (b) study characteristics, such as the instrument used to measure handedness, the length of the questionnaire used, the response format, the year of the publication of the study, whether the measurement of handedness was the main purpose of the study, and whether handedness information was collected by self-report or not. Finally, the heterogeneity among the included studies and the presence of small study bias were assessed.

Method

Study Selection

The list of studies that were entered into the meta-analysis from October 2007 to June 2018 was compiled in five steps: (a) PubMed was searched using the search terms *handedness AND (sex OR gender) NOT animal* NOT child* NOT adolescent* NOT infant* NOT imaging NOT functional NOT structural*, (b) PsycINFO was searched using the terms *handedness OR hand*, (c) the cited literature of all articles that were eligible for inclusion was scanned, (d) the papers where the included studies were referenced were sought using the online database Google Search, and (e) an e-mail request (where e-mail addresses could be retrieved) was sent for missing or unpublished data to the authors of studies that were of our interest, to ensure that no pertinent study, published or unpublished, had been overlooked. Our search strategy was based on the strategy followed by Papadatou-Pastou, Martin, Munafò, and Jones (2008). All their included studies were entered to represent the years 1927- (September) 2007, but was expanded to include steps *d* and *e* (described above). Data collection ended in June 2018 and 200 studies were included in the meta-analysis. Details about the method of literature search and data extraction between October 2007 and June 2018 are shown in Figure 1. Data extraction for the post October 2007 studies was performed by Marietta Papadatou-Pastou and Eleni Ntolka and disagreements were resolved by discussion. Intercoder agreement was 95%. The PRISMA statement (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009) on reporting items for systematic reviews and meta-analyses was followed.

Inclusion and Exclusion Criteria

The following criteria were set for inclusion of a dataset in the systematic review:

(a) Participants: Unless stated otherwise, we assumed that participants were healthy, heterosexual singletons. Data from participants acting as controls to twins or pathological populations were used (e.g., twin controls: Heikkilä et al., 2015; schizophrenia controls: Dane et al., 2009; Dragovic, Milenkovic, & Hammond, 2008; Narr et al., 2007; schizophrenia and bipolar disorder controls: Ravichandran et al., 2017; controls to homosexuals: Xu & Zheng, 2017; Yule et al., 2014).

(b) Age: Participants were over the age of 16 years old. If aggregate data were presented across ages (e.g., "15–70" years; Ellis, Ellis, & Marshall, 1988; "9–83" years; Suar et al., 2013) where the majority of participants were over 16 years., these data were used (Dane & Erzurumluoglu, 2003, were the mean age was 15.81 was also included).

(c) Publication language: Articles were written in English, as this is the language used by most scientific literature. An exception was made for the Azémar and Stein (1994) study, as the data were reported in Raymond et al. (1996).

(d) Handedness assessment: Handedness was measured in terms of preference, not hand skill.

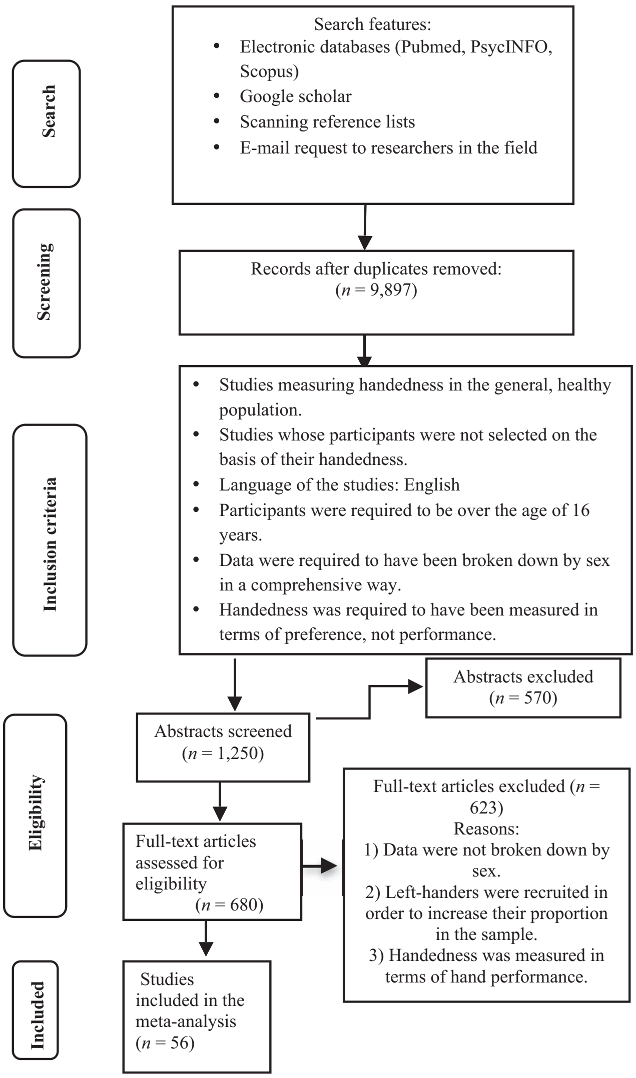

Figure 1. Flow diagram for the search (October 2007–June 2018) and inclusion criteria for studies in the systematic review and meta-analysis. The figure was created according to the guidelines of the PRISMA statement (Moher et al., 2009).

(e) No selection on the basis of handedness: Studies were excluded if participants were selected on the basis of their handedness, either to achieve exclusively right-handed samples or to increase the proportion of left-handed participants (e.g., Christman, Prichard, & Corser, 2015; Lake & Bryden, 1976; Liederman & Healey, 1986; Tan, 1983).

Different studies classified their participants into different handedness groups. The most used classifications were Right-Mixed-Left (R-M-L), Right-Left (R-L), and Right-nonRight (R-nonR). When more complex classifications were used (e.g., right-, right mixed-, left mixed-, and left-handed or seven-class classifications), they were converted to R-M-L when an odd number of classifications was used and R-L when an even number was used. Mixed-handedness included the middle handedness category, as defined and operationalized by the different studies included in the meta-analysis. For example, some studies named the middle category "mixed" (e.g., Hatta & Kawakami, 1995), while others named the participants in the middle category "ambidextrous" (e.g., Chisnall, 2010; Holder, 1992; Jung & Jung, 2009). When two or more samples from different geographical areas (e.g., de la Fuente, Casasanto, Román, & Santiago, 2015) or from different age groups (Ocklenburg et al., 2016) were reported in the same article, they were treated as separate data sets. Nevertheless, if a sample was subdivided into categories not meaningful for this systematic review, then all data were treated as a single dataset. For example, in the case of Lien et al. (2015) the handedness data from the parents and the siblings of college students were merged into a single dataset and in the case of Marmolejo-Ramos et al. (2017) three different college student samples were merged into one dataset. In the case of data sets that were published more than once (e.g., Annett, 1999; Narr et al., 2007; Tsuang et al., 2016) these were included only once. Because a robust sex difference has been shown in a large meta-analysis from our group (Papadatou-Pastou et al., 2008), studies in which information about the gender of each handedness group was not provided were not included (e.g., Corballis, Hattie, & Fletcher, 2008). Data needed to be broken down by handedness groups and sex in a format that provided arithmetic data that could be used in the present analysis (i.e., not reporting only laterality quotients or *p* values or providing only graphical representations of data).

Moderator Variables

The variables that were extracted to test for possible moderating effects on the prevalence of handedness were the following (for a more detailed description see Papadatou-Pastou et al., 2008).

Instrument. The studies were coded for instrument using six different groupings, representing the most popular instruments used to measure handedness in the present dataset. These were: (a) Annett's Hand Preference Questionnaire (8-, 10-, 12-, and 23-item versions), (b) the Edinburgh Handedness Inventory (EHI; 10-item version), (c) writing hand, (d) self-classification, (e) the Briggs and Nebes modification of Annett's Hand Preference Questionnaire, (f) the four items on handedness from Coren and Porac's Laterality Inventory, and (g) observation or information from official records.

Classification scheme. The following schemes were used: R-M-L, R-L, and R-nonR.

Response format. The response formats of the different instruments were grouped as follows: (a) binary forced choice format: this group includes the cases where participants had to make a forced choice (right or left) as well as the cases where participants had to tick a box next to a picture showing their hand posture; (b) 3-point graded response format: this group includes the cases where the response format was worded as follows: "right, both, or left," "right, either, or left," "right, equally, or left," "right, ambidextrous, or left," "always right, either right or left, or always left"; (c) 5-point graded response format, such as Likert scales ranging from "always use the left hand" to "always use the right hand"; and (d) the graphic graded response format, that is the response format allowed in the original version of the EHI. The response format features two columns labeled right and left and participants are asked to indicate their preferences in the use of hands for the activities listed in the questionnaire by putting + in the appropriate column. For the items for which their preference is so strong that they would never try to use the other hand unless absolutely forced to, they are asked to put ++. If it is the case that participants are really indifferent they are asked to put + in both columns.

Ancestry. Rarely was information about ancestry reported, but it was rather inferred from the location in which the testing took place, resulting in three groupings: sub-Saharan African, European, and East Asian.

Education. Education was considered to be higher in individuals who had entered college (college students, faculty, and professionals) than all the other populations, corresponding to two groupings of educational status.

Additionally, information on whether the measurement of handedness was the main purpose of the study, whether participants belonged to a sporting elite (e.g., Loffing, 2017), and whether the data were collected by self-report were also extracted from the studies, using a "yes/no" coding. To test for the possible moderating effects of the year of publication of the studies, mean age of participants, and the length of the questionnaire (i.e., number of questionnaire items used) numerical values were used. Year of publication was also used as a categorical variable with the groupings (a) <1976, (b) 1976–1985, (c) 1986–1995, (d) 1996–2007, and (e) 2008–2019. Not all studies reported information for each of the above moderator variables.

Statistical Analysis

Meta-analysis was carried out in R using the robumeta package (Fisher & Tipton, 2015). The variation in the classification schemes used in the original studies did not allow for a single, overall analysis to take place without losing important information. Therefore, studies were assigned to at least one of five groups, according to the classification schemes they used. The groups, which were analyzed in separate meta-analyses, were as follows:

1. Left-handedness (total): This comparison represents the overall presence of left-handedness (in the case of R-L and R-M-L classifications) or nonright-handedness (in the case of R-nonR classifications). Therefore, information was included from all the data sets, regardless of the classification scheme used.[1]

2. Nonright-handedness: Nonright-handers correspond to participants who were classified as nonright-handers in data sets where an R-nonR classification was used.

3. Left-handedness (forced choice): Left-handers by forced choice correspond to participants who were classified as left-handers in data sets where an R-L classification was used.

4. Left-handedness (stringent): Stringent left-handers correspond to participants who were classified as left-handers in data sets where an R-M-L classification was used.

5. Mixed-handedness: Mixed-handers correspond to participants who were classified as mixed-handers in data sets where an R-M-L classification was used.

The following steps were followed.

Step 1. Handedness prevalence calculation: The atypical handedness rate (the number of left-, mixed-, or nonright-handers in each dataset divided by the total number of participants) was calculated for each dataset independently (with corresponding 95% confidence intervals [CI]). A value of zero represents the absence of atypical-handers or a prevalence of 0%.

Step 2. Meta-analysis was carried out in R using the robumeta package (Fisher & Tipton, 2015) to perform metaregression using correlated robust variance estimation (RVE) models.

Step 3. The homogeneity assumption within each grouping was tested using the I^2 index indicating the variance explained by study heterogeneity, and the τ^2 index specifying variance between studies statistics. According to Higgins, Thompson, Deeks, and Altman (2003), the I^2 index levels can be described as low, moderate, and high, when they fall close to 25%, 50%, and 75%, respectively.

Step 4. The Papadatou-Pastou et al. (2008) meta-analysis showed in a robust way that men are 23% more likely to be left-handed than women. Thus, sex was used as a moderator in each grouping and the handedness prevalence of men and women was compared using the t statistic (and corresponding p value).

Step 5. To investigate the presence of small study bias we used the funnel plot graphical test (funnel() function), Egger's regression test (regtest() function), and Duval and Tweedie's (2000) trim and fill method (trimfill() function) of the R metafor package (Viechtbauer, 2010). Small study bias may be caused by factors such as systematic differences between small and large studies or by publication bias that can exist when studies that do not produce the expected outcome remain disproportionately unpublished. Therefore, the published data sets present a nonrandom sampling of the data sets that have investigated a given research question.

Step 6. Heterogeneity in a dataset may be caused by the presence of moderator variables. Although all groupings were found to be heterogeneous, a moderator variables analysis was conducted only for the left-handedness (total) grouping, as this was the most inclusive one.

Data Availability

All data sets and code used for this analysis have been uploaded to the Open Science Framework repository (https://osf.io/wqf7j/) and as additional online material in this submission.

Results

A total of k_t = 200 studies were included in the different analyses, comprising k_d = 262 separate data sets and totaling n_t = 2,396,170 individuals (n_m = 1,112,365 male, n_f = 1,283,805 female). Details of individual studies are shown in Table 1 and details of moderator variables in Table 2. The prevalence rates found for each grouping below are shown in Table 3 and the

[1] Following Papadatou-Pastou et al. (2008), in the case of three studies where both the R–L and the R–M–L classifications were available for the same measures, information from the latter classification was used (Arning et al., 2015; Brito, Brito, Paumgartten, & Lins, 1989; Saunders & Campbell, 1985).

Table 1
Details of Studies Included in the Meta-Analyses

Study	*N* (men)	*N* (women)	*N* (total)	Geographical location	% Left-handedness (total)		% Left-handedness forced choice		% Left-handedness stringent		% Mixed-handedness		% Nonright-handedness		Measure of handedness	Notes
					M	F	M	F	M	F	M	F	M	F		
Aggleton, Kentridge, and Good (1994)	1,006	532	1,538	U.K.	12.52	12.59	12.52	12.59							Writing hand	Data also reported from 10-item Edinburgh Handedness Inventory (EHI)
Aggleton and Wood (1990)	131	213	344	U.S./U.K.	9.92	6.57	9.92	6.57							Hand used for bowling (official records/self-report of bowling hand)	
	199	164	363		8.04	14.63			8.04	14.63	3.52	3.05				
Anakwe, Huntley, and McEachan (2007)	172	78	250	U.K.	8.72	14.10	8.72	14.10							Self-classification (if no preference for the dominant hand was claimed, the writing hand was taken into account)	
Annett (1973)	2,151	1,493	3,644	U.K.	11.76	11.45	11.76	11.45							Writing hand	
	3,644	3,644	7,288		4.39	3.70	4.39	3.70								
Annett (1979)	397	407	804	U.K.	6.55	8.60	6.55	8.60							Writing hand	Information on the handedness of siblings reported as well, but age was unknown, possibly under 16 years
	322	368	690		12.73	4.62	12.73	4.62							Report by spouses on writing hand	
	756	784	1540		6.35	5.99	6.35	5.99							Filial report on writing hand	
Annett (1985)	321	321	642	—	6.55	8.60	6.55	8.60							Not reported	Data reported in Annett (2002) and Raymond, Pontier, Dufour, and Møller (1996)
	357	390	747	—	32.75	40.05	32.75	40.05							Not reported	
	128	96	224	—	12.73	4.62	12.73	4.62							Hand holding the racket (tennis players)	
	33	33	66	—	6.35	5.99	6.35	5.99							Hand holding the racket (tennis players)	
Annett (2002)	100	100	200	—	15.00	11.00	15.00	11.00							Hand holding the racket	
Annett (2008)	289	289	578	U.K.	14.88	11.76	14.88	11.76							Writing hand	Participants in the first two data sets were reported to have completed the Annett Hand Preference Questionnaire, but only information on writing hand was given in the article.
	383	1,287	1,670		10.97	11.03	10.97	11.03								
	1,682	1,682	3,364		12.19	9.51	12.19	9.51								
Annett and Kilshaw (1982)	667	883	1,550	U.K.	7.80	8.49	7.80	8.49							Writing hand	Participants were reported to have also completed the 8-item and 12-item Annett's Handedness Questionnaires, but writing hand was used in the left-handedness (total) meta-analysis.
Ardila and Rosselli (2001)	2,686	4,255	6,941	Colombia	4.99	4.21			4.99	4.21	4.39	3.10			Self-classification	Participants were from Colombia, therefore, not fitting any of the three ancestry categories used.
Arning et al. (2015)	430	626	1,056	Germany	6.98	6.07			6.98	6.07	3.02	3.99			EHI	The numbers of the handedness groups were calculated based on the percentages given. The calculations were based on the trichotomous categorization of handedness.
Ashton (1982)	1,029	998	2,027	U.S., Japan	7.09	7.11	7.09	7.11							Writing hand/hand usage	Data reported on hand usage as well on the question "which hand do you use the most?"
	397	443	840		1.01	1.58	1.01	1.58								
	387	371	758		5.17	5.66	5.17	5.66								
Azémar and Stein (1994)	1,686	804	2,490	—	28.41	26.00	28.41	26.00							Hand holding sword/foil	Data reported in Raymond et al. (1996)
Bakan and Putnam (1974)	151	249	400	Canada	18.54	8.43	18.54	8.43							Writing hand	
Barut, Ozer, Sevinc, Gumus, and Yunten (2007)	343	290	633	Turkey	18.95	11.72			18.95	11.72	7.29	2.76			10-item EHI	
Beckman and Elston (1962)	492	489	981	Sweden	5.28	5.73	5.28	5.73							Not reported	

Table 1 (*continued*)

Study	N (men)	N (women)	N (total)	Geographical location	% Left-handedness (total)		% Left-handedness forced choice		% Left-handedness stringent		% Mixed-handedness		% Nonright-handedness		Measure of handedness	Notes
					M	F	M	F	M	F	M	F	M	F		
Betancur, Vélez, Cabanieu, LeMoal, and Neveu (1990)	93	112	205	France	9.68	9.82			9.68	9.82	19.35	16.07			Modified version of 10-item EHI	The participants were controls to allergic patients.
Birkett (1981)	54	71	125	U.K.	38.89	43.66	38.89	43.66							10-item EHI	
Briggs and Nebes (1975)	831	768	1,599	U.S.	8.90	9.38			8.90	9.38	5.66	4.82			12-item Briggs & Nebes modification of Annett's questionnaire	
Brito, Brito, Paumgartten, and Lins (1989)	471	488	959	Brazil	3.40	2.66	3.40	2.66							10-item EHI	Participants were from Brazil, therefore, not fitting any of the three ancestry categories used.
Bryden (1977)	620	486	1,106	Canada	12.10	9.05	12.10	9.05							Writing hand	1. Data also reported for self-classification 2. The participants were also administered the Crovitz-Zener and Oldfield's questionnaires, but only mean scores for each question for M-F were given.
Bryden (1989)	334	460	794	Canada	11.08	7.39	11.08	7.39							Eight-items from EHI	
Bryden and Roy (2005)	47	106	153	Canada	17.02	8.49	17.02	8.49							Writing hand	
Buchtel and Rueckert (1984)	365	375	740	U.S.	13.70	13.07	13.70	13.07							Writing hand	
Cannon et al. (1995)	21	22	43	Ireland	4.76	9.09			4.76	9.09	19.05	4.55			10-item EHI	The participants were controls to patients with schizophrenia.
Carrière and Raymond (2000)	133	113	246	Cameroon	9.02	7.08	9.02	7.08							Observation of which hand was used to hold the machete	Children were also included in the sample, but the age variable was not significant.
Casey and Brabeck (1989)	119	314	433	U.S.	26.89	25.48							26.89	25.48	10-item EHI	
Chamberlain (1928)	2,177	2,177	4,354	U.S.	4.18	2.94	4.18	2.94							Writing hand (by filial report)	The reporters' data were not included, as they were all male as well as the data on their siblings handedness because their age was unknown.
Chapman and Walsh (1973)	633	290	923	Australia	12.16	13.10			12.16	13.10	1.11	1.03			Throwing a ball	
Chapman and Chapman (1987)	2,786	3,039	5,825	U.S.	6.89	6.19			6.89	6.19	12.49	9.90			13-item questionnaire	
Chen, Sachdev, Wen, and Anstey (2007)	184	227	411	Australia	10.87	10.57	10.87	10.57							EHI	
Chisnall (2010)	185	117	302	Canada	14.05	15.38			14.05	15.38	1.62	0.85			Writing hand	Participants from the age groups 0–10 and 10–20 were excluded due to the age criterion. Only 302 participants remained.
Çiçek, Arabaci, and Canakçi (2010)	720	790	1,510	Turkey	9.17	7.85	9.17	7.85							EHI	
Coren (1989)	810	1,086	1,896	Canada	10.37	8.84	10.37	8.84							The four-items for handedness from the Lateral Preference Inventory by Coren	
Coren (1993)	1,375	1,932	3,307	Canada	11.78	9.21	11.78	9.21							The four-items for handedness from the Lateral Preference Inventory by Coren	
Coren (1995)	1,298	1,298	2,596	Canada	9.78	8.32	9.78	8.32							The four-items for handedness from the Lateral Preference Inventory by Coren	The data on the handedness of the reporters and their siblings were not broken down by sex.
Coren and Porac (1979)	802	956	1,758	Canada	11.35	10.46	11.35	10.46							Writing hand	
Coren and Porac (1980)	1,284	1,477	2,761	Canada	11.45	10.49	11.45	10.49							The four-items for handedness from the Lateral Preference Inventory by Coren	
	684	726	1,410		12.43	9.92	12.43	9.92								

(*table continues*)

Table 1 (*continued*)

Study	*N* (men)	*N* (women)	*N* (total)	Geographical location	% Left-handedness (total)		% Left-handedness forced choice		% Left-handedness stringent		% Mixed-handedness		% Nonright-handedness		Measure of handedness	Notes
					M	F	M	F	M	F	M	F	M	F		
Coren, Searleman, and Porac (1986)	467	713	1,180	Canada	12.85	8.42	12.85	8.42							The four items for handedness from the Lateral Preference Inventory by Coren	
Cornell and McManus (1992)	142	124	266	U.K.	7.75	13.71	7.75	13.71							Writing hand	
Cosenza and Mingoti (1993)	1,040	921	1,961	Brazil	10.96	7.82	10.96	7.82							10-item EHI	Participants were from Brazil, therefore, not fitting any of the three ancestry categories used.
	6,226	8,403	14,629		8.88	7.14	8.88	7.14								
Cosenza and Mingoti (1995)	6,654	8,735	15,389	Brazil	8.79	7.17	8.79	7.17							10-item EHI	
Cuff (1931)	17	92	109	U.S.	5.88	7.61	5.88	7.61							Eight-item questionnaire	The paper reported data on children as well, not used here.
Curt, De Agostini, Maccario, and Dellatolas (1995)	777	832	1,609	France	8.75	8.77	8.75	8.77							12-item hand preference questionnaire	
Dane and Erzurumluoğlu (2003)	160	166	326	Turkey	19.38	15.06	19.38	15.06							10-item EHI	
Dane (2019)	52	55	107	Nigeria	19.23	5.45	19.23	5.45							EHI	Calculations based on unpublished raw data kindly provided by the author.
	125	75	200	Nigeria	8.00	8.00	8.00	8.00								
Dane et al. (2009)	60	58	118	Turkey	6.67	3.45			6.67	3.45	21.67	17.24			EHI	
Dargent-Paré, De Agostini, Mesbah, M., and Dellatolas (1992)	312	340	652	Algeria	5.45	5.88	5.45	5.88							12-item questionnaire	
	374	311	685	Greece	6.68	5.79	6.68	5.79								
	502	199	701	Italy	8.37	4.52	8.37	4.52								
	375	350	725	Spain	8.00	4.86	8.00	4.86								
	1,024	1,277	2,301	France	8.50	9.48	8.50	9.48								
De Agostini, Khamis, Ahui, and Dellatolas (1997)	382	382	764	Ivory Coast	9.16	4.97	9.16	4.97							Filial report	
	397	358	755		5.04	5.03	5.04	5.03							10-item questionnaire	
	734	736	1,470		6.40	5.03	6.40	5.03							Filial report	
de Kovel, Carrión-Castillo, and Francks (2019)	228,554	272,893	501,447	41% U.K., 59% other	10.41	8.45			10.41	8.45	2.12	1.40			Self-classification	Official records from U.K. Biobank dataset.
de la Fuente, Casasanto, Román, and Santiago (2015)	43	51	94	Morocco	0.00	0.00	0.00	0.00							EHI	Despite collecting large samples, in 3 out of 4 datasets, no LH was detected.
	36	35	71	Spain	0.00	0.00	0.00	0.00								
	16	13	29	Spain	12.50	53.85	12.50	53.85							Writing hand	
	25	15	40	Morocco	0.00	0.00	0.00	0.00							Four-item handedness performance measure	
DeLisi et al. (2002)	135	153	288	U.S., U.K., Italy	9.63	3.27			9.63	3.27	9.63	7.84			23-item Annett's questionnaire	
Demura et al. (2006)	2,429	1,128	3,557	Japan	6.55	3.19			6.55	3.19	1.81	2.84			10-item EHI Handedness Inventory	Data also reported on each participant's dominant hand for various sports.
Dinsdale, Reddon, and Hurd (2011)	188	207	395	Canada	11.17	9.18			11.17	9.18	0.00	0.48			EHI, writing hand	The writing hand was taken into account for the meta-analysis.
Dirnberger (2012)	401	614	1,015	Austria	8.23	6.51	8.23	6.51							EHI	2 MH men excluded because "For two male participants with L = 0 the direction of handedness could not be calculated, and they were, therefore, excluded from further analysis."
Downey (1927)	421	300	721	U.S.	6.18	3.33	6.18	3.33							Five-item questionnaire	Data also reported on a group of adult and juvenile delinquents, inmates of institutions for the feebleminded and insane and boys and girls in special classes for subnormal children, but not used here.
Dragovic, Milenkovic, and Hammond (2008)	357	430	787	Australia	12.89	9.07	12.89	9.07							EHI, writing hand	The writing hand was taken into account for the meta-analysis.

Table 1 (*continued*)

Study	*N* (men)	*N* (women)	*N* (total)	Geographical location	% Left-handedness (total)		% Left-handedness forced choice		% Left-handedness stringent		% Mixed-handedness		% Nonright-handedness		Measure of handedness	Notes
					M	F	M	F	M	F	M	F	M	F		
Dronamraju (1975)	213	218	431	India	15.49	7.80	15.49	7.80							Hand used to hold a brush	
	43	43	86		6.98	4.65	6.98	4.65								
Elalmiş and Tan (2005)	11,492	10,969	22,461	Turkey	7.96	7.19			7.96	7.19	2.64	2.35			Self-classification	
Elalmis and Tan (2008)	91	106	197	Turkey	16.48	6.60	16.48	6.60							Writing hand	
Elias, Saucier, and Guylee (2001)	117	424	541	Canada	14.53	8.96	14.53	8.96							Self-classification	
Ellis, Ellis, and Marshall (1988)	3,070	3,507	6,577	U.S.	7.79	6.87	7.79	6.87							10-item EHI	
Elneel, Carter, Tang, and Cuschieri (2008)	32	20	52	Italy	37.50	0.00			37.50	0.00	0.00	0.00			Handedness questionnaire (direct questions)	
Espírito-Santo et al. (2017)	157	185	342	Portugal	0.64	0.54			0.64	0.54	43.31	37.84			EHI	
Fagard, Chapelain, and Bonnet (2015)	261	443	704	France, England	11.11	10.61			11.11	10.61	4.60	2.26			15-item handedness questionnaire	Calculations based on raw data kindly provided by the authors.
Faurie et al. (2008)	4,720	7,175	11,895	France	10.38	9.41	10.38	9.41							Self-classification	The numbers of the handedness groups were calculated based on the percentages given.
	10,437	3,517	13,954	France	10.55	9.35	10.55	9.35							Six-item handedness questionnaire	
Fry (1990)	211	155	366	U.S.	15.64	12.90	15.64	12.90							Offspring: 10-item EHI	Data on siblings' handedness was also reported, but was excluded because age was not reported.
	359	362	721		11.70	11.88	11.70	11.88							Parents: filial report of writing hand	
Genetta-Wadley and Swirsky-Sacchetti (1990)	30	30	60	U.S.	10.00	3.33	10.00	3.33							12-item Annett's Handedness Questionnaire	
Gilbert and Wysocki (1992)	513,393	664,114	1,177,507	U.S.	12.60	9.90							12.60	9.90	Writing hand and throwing hand	
Gladue and Bailey (1995)	76	73	149	U.S.	35.53	28.77							35.53	28.77	10-item Annett Handedness Questionnaire	The participants were controls to homosexual individuals.
Götestam (1990)	110	125	60	Norway	9.09	9.60			9.09	9.60	0.91	3.20			Writing hand	Percentages were given when reporting results on writing hand, adding up to 99.1% for men and 96.8% for women. It was, therefore, assumed that 0.9% of men and 3.2% of women used equally both hands for writing, making up the mixed category.
			175		10.00	12.80	10.00	12.80							Four-item questionnaire	
Green and Young (2001)	144	140	284	U.K.	23.61	27.14			23.61	27.14	27.78	25.71			Six-item questionnaire	The participants were controls to transsexual participants.
Grouios, Tsorbatzoudis, Alexandris, and Barkoukis (2000)	578	534	1,112	Greece	15.92	13.67	15.92	13.67							12-item Briggs-Nebes modification of Annett's questionnaire	
	623	564	1,187		10.11	7.80	10.11	7.80								
Gunstad, Spitznagel, Luyster, Cohen, and Paul (2007)	319	324	643	n/a	16.61	16.36							16.61	16.36	EHI	Data from the Brain Resource International Database
Gupta, Sanyal, and Babbar (2008)	63	21	84	New Delhi	14.29	14.29	14.29	14.29							Self-classification	
Gur and Gur (1977)	100	100	200	U.S.	16.00	6.00	16.00	6.00							23-item Raczkowski et al.'s questionnaire	
Halpern, Haviland, and Killian (1998)	85,118	67,535	152,653	U.S.	12.60	10.40	12.60	10.40							Writing hand	
Hannay, Ciaccia, Kerr, and Barrett (1990)	578	607	1,185	U.S.	4.33	4.45			4.33	4.45	27.51	16.14			10-item questionnaire	
Hannula, Bloigu, Majamaa, Sorri, and Mäki-Torkko (2012)	383	467	850	Finland	4.18	6.42	4.18	6.42							Self-classification	The numbers of the handedness groups were calculated based on the percentages given.
Harburg, Feldstein, and Papsdorf (1978)	364	371	735	U.S.	7.69	7.03	7.69	7.03							Self-classification	Data from survey interviews from a larger project conducted in Detroit between 1968–1969.
	377	384	761		8.24	5.12	8.24	5.12								
Harburg, Roeper, Ozgoren, and Feldstein (1981)	278	373	651	U.S.	14.39	12.33	14.39	12.33							Writing hand	
	247	255	502		7.69	5.49	7.69	5.49								

(*table continues*)

Table 1 (*continued*)

Study	*N* (men)	*N* (women)	*N* (total)	Geographical location	% Left-handedness (total)		% Left-handedness forced choice		% Left-handedness stringent		% Mixed-handedness		% Nonright-handedness		Measure of handedness	Notes
					M	F	M	F	M	F	M	F	M	F		
Harris and Gitterman (1978)	317	39	356	U.S.	7.26	7.69	7.26	7.69							12-item Briggs & Nebes handedness questionnaire	Eight additional female left-handers were added to provide more power to the results of the study, but were subtracted from the numbers reported here.
Harvey (1988)	280	118	398	U.K.	17.14	11.86	17.14	11.86							10-item EHI	Data were also reported on 838 fifth year pupils as well as on 1,000 sixth year pupils, which were excluded from the meta-analysis.
Hatta and Kawakami (1995)	517	1,183	1,700	Japan	6.19	4.23			6.19	4.23	6.58	5.58			10-item questionnaire	
Hatta and Nakatsuka (1976)	488	711	1,199	Japan	4.30	2.25	4.30	2.25							10-item questionnaire	
Heim and Watts (1976)	109	289	398	U.K.	16.51	9.69	16.51	9.69							Writing hand	Data on younger participants as well.
	340	152	492		10.59	5.92	10.59	5.92								
Heikkilä et al. (2015)	864	927	1,791	Finland	9.95	5.83	9.95	5.83							Writing hand	The subgroup of the singletons (controls to twins) was used for the meta-analysis.
Hicks, Dusek, Larsen, and Pellegrini (1980)	257	323	580	U.S.	11.28	11.15	11.28	11.15							12-item Briggs & Nebes handedness questionnaire	
Hicks and Kinsbourne (1976)	1,101	1,101	2,202	U.S.	9.36	9.36	9.36	9.36							Filial report of writing hand	Information about the handedness of the students was also collected, but reported only in the form of laterality quotients.
Hicks, Pellegrini, and Evans (1978)	366	362	728	U.S.	11.20	5.80	11.20	5.80							12-item Briggs & Nebes modification of Annett's questionnaire	All ambidextrous participants were excluded from the sample.
Holder (1992)	70	244	314	U.S.	10.00	9.02			10.00	9.02	25.71	19.26			Self-classification	Unpublished Masters of Philosophy (M.Phil) thesis
Holtzen (1994)	82	178	260	U.S.	4.88	8.43			4.88	8.43	2.44	1.12			Five items from the EHI	The participants were controls to homosexual participants.
Holtzen (2000)	1,404	281	1,685	—	5.20	4.98	5.20	4.98							Hand holding the racket	
Hoogmartens and Caubergh (1987)	52	76	128	Belgium	11.54	7.89	11.54	7.89							The four items for handedness from the Lateral Preference Inventory by Coren	
Hoosain (1990)	220	336	556	Hong Kong	2.73	0.89			2.73	0.89	5.45	1.79			10-item questionnaire	
Huang and Sejdić (2013)	9	11	20	U.S.	11.11	18.18			11.11	18.18	0.00	9.09			EHI	
Ida and Bryden (1996)	333	322	655	Japan	1.80	0.93	1.80	0.93							Writing hand	Data on 65 other items as well, but no laterality quotient given.
	245	375	620	Canada	9.80	7.73	9.80	7.73								
Inglis and Lawson (1984)	940	940	1,880	U.S.	9.89	8.19	9.89	8.19							Three-item questionnaire: Self-classification, observation of writing hand, and hand usage	
Iwasaki, Kaiho, and Iseki (1995)	696	1,059	1,755	Japan	1.15	0.66	1.15	0.66							Writing hand	Data also reported from a 15-item inventory.
Jung and Jung (2009)	1,010	875	1,885	Korea	5.84	5.49			5.84	5.49	7.13	6.86			13-item handedness questionnaire	Participants from the age group 10–20 years were excluded because of the age criterion. Only 1,885 participants remained.
Kalaycıoğlu, Kara, Atbaşoğlu, and Nalçacı (2008)	22	27	49	Turkey	4.55	14.81							4.55	14.81	13-item handedness questionnaire	
Kalichman, Korostishevsky, and Kobyliansky (2008)	592	595	1,187	Russia	9.08	9.97	9.08	9.97							Writing hand, observation of a three-item handedness performance measure	The writing hand was taken into account for the meta-analysis.
Kauranen and Vanharanta (1996)	20	20	40	Finland	0.00	10.00	0.00	10.00							Self-classification	
	20	20	40		15.00	10.00	15.00	10.00								
	20	20	40		5.00	15.00	5.00	15.00								
	20	20	40		10.00	0.00	10.00	0.00								

Table 1 (*continued*)

Study	*N* (men)	*N* (women)	*N* (total)	Geographical location	% Left-handedness (total)		% Left-handedness forced choice		% Left-handedness stringent		% Mixed-handedness		% Nonright-handedness		Measure of handedness	Notes
					M	F	M	F	M	F	M	F	M	F		
	20	20	40		5.00	0.00	5.00	0.00								
Klum et al. (2012)	387	363	750	Germany	6.72	6.06	6.72	6.06							Self-classification (in case of uncertainty, the writing hand was taken into account)	
Kuderer and Kirchengast (2016)	21	34	55	Austria	38.10	52.94			38.10	52.94	14.29	17.65			Observation of 22 activities	
Lai, Serra, Petretto, Masala, and Preti (2014)	506	517	1,023	Italy	10.87	9.67			10.87	9.67	1.19	1.35			Annett Hand Preference Questionnaire, writing hand	The writing hand (reported as noncorrected in the paper) was taken into account for the meta-analysis.
Lambert and Hallett (2009)	170	716	886	New Zealand	15.29	13.41			15.29	13.41	1.76	0.70			EHI	Because of lack of usable arithmetic data, out of the 10 items of EHI only the writing hand item was taken into account for the meta-analysis. The numbers of the handedness groups were calculated based on the percentages given.
Lansky, Feinstein, and Peterson (1988)	380	508	888	U.S.	12.63	8.86	12.63	8.86							Writing hand	1. The classification by the authors was R/ R mixed/ L mixed/ L, using a 5-item questionnaire (L: left hand for all five activities, L mixed: write with the left hand, but do any other activities with the right hand or write most of the time with the left hand, and corresponding categories for the R.) Data was broken down to R-L; thus, using writing hand as the measure.
	327	526	853		5.20	15.97	5.20	15.97								
	74	111	185		12.16	11.71	12.16	11.71								
	64	93	157		7.81	4.30	7.81	4.30								
Lee-Feldstein and Harburg (1982)	525	628	1,153	U.S.	11.24	9.55	11.24	9.55							Writing hand	
Leiber and Axelrod (1981)	867	899	1,766	U.S.	12.00	9.01			12.00	9.01	3.58	2.34			Self-classification	
	574	137	711		9.06	5.11			9.06	5.11	2.44	0.00				
Lester, Werling, and Heinle (1982)	670	1,498	2,168	U.S.	10.90	6.21	10.90	6.21							Not reported	
Levander and Schalling (1988)	506	415	921	Sweden	7.91	9.88			7.91	9.88	1.98	1.93			Writing hand	The same participants were also classified with the Karolinska Hospital (KH) hand preference inventory as R-M-L.
Lien, Chen, Hsiao, and Tsuang (2015)	249	377	626	Taiwan	4.82	1.86	4.82	1.86							Annett Hand Preference Questionnaire	Because of lack of usable arithmetic data, out of the 10 items of the EHI only the writing hand item was taken into account for the meta-analysis. Two data sets (parents and siblings) were combined because of the same variables.
	672	642	1,314	Taiwan	3.42	2.34	3.42	2.34								
Lippa (2003)	350	706	1,056	U.S.	11.43	12.04							11.43	12.04	Self-classification/three-item inventory	The participants were controls to homosexual participants.
Loffing, Sölter, and Hagemann (2014)	408	495	903	Germany	10.05	7.88	10.05	7.88							EHI, Coren's Lateral Preference Inventory	The EHI was taken into account for the meta-analysis. The numbers of the handedness groups were calculated based on the percentages given.

(*table continues*)

Table 1 (*continued*)

Study	N (men)	N (women)	N (total)	Geographical location	% Left-handedness (total)		% Left-handedness forced choice		% Left-handedness stringent		% Mixed-handedness		% Nonright-handedness		Measure of handedness	Notes
					M	F	M	F	M	F	M	F	M	F		
Loffing (2017)	719	766	1,485	Not reported	15.44	10.70	15.44	10.70							Players' task-specific handedness (i.e., throwing, or holding a racket) was obtained from websites or from additional pictures/videos of players in action	Only sports who reported females' handedness as well as males' was taken into account (badminton, squash, table tennis, and tennis).
Lui, Baker, Nfila, Perera, and Stephens (2012)	57	5	62	Ireland	7.02	0.00	7.02	0.00							Waterloo handedness questionnaire, Orthopaedic Handedness Questionnaire	
Lyle, Chapman, and Hatton (2013)	57	106	163	U.S.	64.91	33.02	64.91	33.02							EHI	Consistent and inconsistent left-handers were considered to be one class, the left-handers, for the purposes of the meta-analysis. Also, consistent and inconsistent right-handers were grouped to form the right-handedness class.
Maehara et al. (1988)	1,681	778	2,459	Japan	15.53	14.01							15.53	14.01	10-item EHI	This study had 8,693 participants from 6 to 94 years old. Only reported here is the percentage given for the age group 25–40, since the total average could not be used, because of the age limitation.
Marchant-Haycox, McManus, and Wilson (1991)	287	109	396	U.K., U.S.	7.67	6.42	7.67	6.42							Nine-item hand preference inventory	The participants were controls to homosexual participants.
Marmolejo-Ramos et al. (2017)	475	685	1160	England, India, Japan, Spain, Vietnam, Germany	14.11	8.32	14.11	8.32							Self-classification	Three data sets were combined.
Martin and Porac (2007)	731	904	1,635	Brazil	11.08	10.18	11.08	10.18							Self-classification	Participants were from Brazil, therefore, not fitting any of the three ancestry categories employed. Participants also completed the Paraense Lateral Preference Inventory.
Mascie-Taylor, MacLarnon, Lanigan, and McManus (1981)	79	62	141	U.K.	21.52	9.68	21.52	9.68							Writing hand	
Mascie-Taylor (1980)	193	193	386	U.K.	8.81	7.25	8.81	7.25							Writing hand/seven-item questionnaire	The handedness of the offspring was also measured, but their data were not included, as they were probably below 16.
McFarland and Anderson (1980)	85	96	181	Australia	7.06	5.21	7.06	5.21							Writing hand	Data on the other items of the EHI reported as well, but no laterality quotient given.
McGee (1976)	46	66	112	U.S.	28.26	9.09	28.26	9.09							Seven items from Annett (1970)	
McGee and Cozad (1980)	615	615	1,230	U.S.	19.67	16.75							19.67	16.75	10-item EHI	Also data on the students' and their siblings' data, but were not used, as the siblings' age was not reported.
McKeever and Riche (1990)	1,116	1,964	3,080	U.S.	12.01	10.34	12.01	10.34							Writing hand	
McManus (1986)	1,106	922	2,028	U.K.	10.04	10.74	10.04	10.74							Self-classification	Unpublished data (reported in McManus, 2019).
Merrell (1957)	72	51	123	U.S.	4.17	3.92	4.17	3.92							Writing hand	
	261	236	497		6.90	6.36	6.90	6.36								
Mészáros et al. (2006)	44	106	150	Hungary	31.82	25.47	31.82	25.47							Structured medical questionnaire	
Milenković, Brkić, and Belojević (2013)	401	801	1,202	Serbia	7.73	3.62	7.73	3.62							Writing hand	
Morley and Caffrey (1994)	1,821	1,993	3,814	U.K.	11.97	11.34			11.97	11.34	0.27	0.25			Writing hand/self-classification	

Table 1 (*continued*)

Study	*N* (men)	*N* (women)	*N* (total)	Geographical location	% Left-handedness (total)		% Left-handedness forced choice		% Left-handedness stringent		% Mixed-handedness		% Nonright-handedness		Measure of handedness	Notes
					M	F	M	F	M	F	M	F	M	F		
Mustanski, Bailey, and Kaspar (2002)	177	205	382	U.S.	10.17	9.76			10.17	9.76	2.82	0.00			Self-classification	The participants were controls to homosexual participants.
Nalçaci, Kalaycioğlu, Çiçek, and Genç (2001)	168	142	310	Turkey	36.31	19.72							36.31	19.72	13-item questionnaire adapted from Chapman and Chapman (1987)	
Narr et al. (2007)	30	37	67	U.S.	23.33	8.11							23.33	8.11	EHI, observation	The EHI was taken into account for the meta-analysis.
Newcombe and Ratcliff (1973)	409	414	823	U.K.	3.67	2.66			3.67	2.66	22.49	11.35			Seven-item questionnaire	
Newcombe et al. (1975)	462	466	928	U.K.	5.84	4.08			5.84	4.08	10.82	8.58			Seven-item questionnaire	R: right hand preferred for all items L: left hand preferred for all items R/L: right hand and left hand, each preferred for at least one item, but no either hand responses R/E: right-hand and either hand, but no left-hand responses L/E: left-hand and either-hand but no right-hand responses R/L/E: right-hand, left-hand, and either–hand, each reported for at least one item.
Nicholls, Orr, Yates, and Loftus (2008)	131	469	600	Australia	12.98	10.23							12.98	10.23	Provins and Cunliffe (1972) questionnaire	
Nicholls, Chapman, Loetscher, and Grimshaw (2010)	405	420	895	n/a	9.14	7.38	9.14	7.38							Annett Hand Preference Questionnaire	Calculations based on raw data kindly provided by the authors.
Nicholls, Thomas, Loetscher, and Grimshaw (2013)	754	2,570	3,324	Europe, Asia	9.42	8.09			9.42	8.09	3.32	1.79			Provins and Cunliffe (1972) questionnaire	The numbers of the handedness groups were calculated based on the percentages given.
Obrzut, Dalby, Boliek, and Cannon (1992)	85	233	318	U.S.	11.76	8.15	11.76	8.15							The first factor of the Waterloo Handedness Questionnaire (14 items)	The participants were controls to learning-disabled adults.
Ocklenburg et al. s (2016)	103	103	206	Germany	5.83	7.77	5.83	7.77							EHI	Calculations based on raw data kindly provided by the authors.
	43	60	103		11.63	8.33	11.63	8.33								
Ofte (2002)	153	240	393	Norway	13.73	14.17	13.73	14.17							Five-item questionnaire	
Oldfield (1971)	400	709	1,109	U.K.	10.00	5.92	10.00	5.92							10-item EHI	
Overby (1994)	427	536	963	U.S.	8.43	7.84			8.43	7.84	6.56	2.80			Self-classification	The participants were controls to college students who obtained elevated scores on the BDI ("dysphoric").
Perelle and Ehrman (1983)	1,320	1,084	2,404	U.S.	20.38	19.56			20.38	19.56	4.32	5.81			13-item questionnaire	
Perelle and Ehrman (1994)	4,881	5,900	10,781	32 countries	10.59	8.49	10.59	8.49							Writing hand	
	10,507	10,751	21,258		5.71	5.75	5.71	5.75								
Peters, Petrie, and Oddie (1981)	130	235	365	Canada	12.31	11.49							12.31	11.49	Four-item questionnaire	
Peters, Reimers, and Manning (2006)	89,697	74,533	164,230	U.K.	12.66	10.50			12.66	10.50	0.56	0.76			Writing hand	
Plato, Fox, and Garruto (1984)	461	244	705	U.S.	6.94	4.10	6.94	4.10							Writing hand	Data also reported on self-classification (R-L) and a 10-item inventory (R-M-L).
Porac (1993)	49	131	180	Canada	8.16	12.21	8.16	12.21							Six-item questionnaire	
	78	154	232		16.67	14.94	16.67	14.94								
	49	78	127		10.20	5.13	10.20	5.13								
	42	51	93		4.76	0.00	4.76	0.00								
Porac, Coren, and Searleman (1983)	450	450	900	Canada	7.56	6.67	7.56	6.67							Writing hand	Also data on the handedness of their children was available (R-L), but the age was not reported.

(*table continues*)

Table 1 (*continued*)

Study	*N* (men)	*N* (women)	*N* (total)	Geographical location	% Left-handedness (total)		% Left-handedness forced choice		% Left-handedness stringent		% Mixed-handedness		% Nonright-handedness		Measure of handedness	Notes
					M	F	M	F	M	F	M	F	M	F		
Porfert and Rosenfield (1978)	1,147	960	2,107	U.S.	14.56	13.96							14.56	13.96	Short questionnaire	
Preti et al. (2011)	1,588	2,644	4,232	Italy	10.14	10.21			10.14	10.21	0.00	0.04			Writing hand	
Preti et al. (2012)	419	585	1,004	Italy	8.59	9.57	8.59	9.57							Writing hand	
Ravichandran, Shinn, Öngür, Perlis, and Cohen (2017)	108	145	253	USA	10.19	7.59							10.19	7.59	Self-classification	
Raymond, Pontier, Dufour, and Møller (1996)	208	142	350	France	16.35	14.79	16.35	14.79							Students: writing hand	
	274	268	542	n/a	16.42	11.19	16.42	11.19							Athletes: hand holding discus, javelin, shot put, or racket	
	42	33	75	France	21.43	18.18	21.43	18.18							Athletes: hand holding discus, javelin, shot put or racket	
Reina, Cavaignac, Trousdale, Laffosse, and Braga (2017)	11	6	17	n/a	18.18	16.67	18.18	16.67							Self-classification	
Reiß and Reiß (1997)	506	430	936	Germany	11.26	6.05							11.26	6.05	The four items for handedness from the Lateral Preference Inventory by Coren	
Reiß, Reiß, and Freye (1998)	556	667	1,223	Germany	7.91	7.05			7.91	7.05	3.06	1.95			Self-classification	Data also on 10-item EHI (R-M-L).
Rife (1940)	1,282	896	2,178	U.S.	9.59	7.59							9.59	7.59	10-item questionnaire	It was not known how many were the students and how many were the siblings.
	687	687	1,374		5.39	5.09							5.39	5.09		
Risch and Pringle (1985)	2,122	2,141	4,263	U.S.	13.05	11.86	13.05	11.86							Offspring: 10-item EHI and self-classification	Among the participants it was not clear who were the students i.e. the reporter and who were the siblings
	1,564	1,564	3,128		12.34	7.29	12.34	7.29								
Robinson, Hurd, Read, and Crespi (2016)	233	475	708	Canada	6.87	5.68			6.87	5.68	8.58	8.21			Waterloo handedness questionnaire	
Rosenstein and Bigler (1987)	14	36	50	U.S.	7.14	5.56	7.14	5.56							10-item EHI	The participants were controls to homosexual participants.
Sakano and Pickenhain (1985)	399	599	998	Japan	5.26	2.84			5.26	2.84	6.77	6.68			Five items from the EHI	It was not clear how the participants scoring 60–80 or (−20)-0 were classified; possibly they were excluded from the sample.
	235	455	690	Germany	7.66	2.42			7.66	2.42	8.94	7.91				
Salmaso and Longoni (1985)	961	733	1,694	Italy	6.76	6.41	6.76	6.41							20-item EHI	
Sanders, Wilson, and Vandenberg (1982)	173	168	341	U.S. (European, Japanese and Chinese participants)	5.78	7.14			5.78	7.14	17.92	13.10			Hand preference questionnaire	
	110	114	224		7.27	6.14			7.27	6.14	26.36	15.79				
	67	76	143		4.48	1.32			4.48	1.32	20.90	10.53				
	24	54	78		4.17	3.70			4.17	3.70	20.83	24.07				
	29	26	55		6.90	7.69			6.90	7.69	17.24	19.23				
	17	21	38		0.00	4.76			0.00	4.76	11.76	33.33				
Saunders and Campbell (1985)	123	249	372	U.S.	17.89	9.24	17.89	9.24							10-item EHI	
Savel (2009)	29	21	50	France	17.24	38.10	17.24	38.10							EHI	
Schachter, Ransil, and Geschwind (1987)	998	119	1,117	U.S.	27.05	15.97							27.05	15.97	10-item EHI	
Searleman and Fugagli (1987)	129	148	277	U.S.	14.73	10.81	14.73	10.81							Writing hand	1. The participants were controls to individuals with diabetes, Crohn's disease, and ulcerative colitis 2. A 7-item questionnaire was also administered to assess strength of hand preference.
Searleman, Porac, and Coren (1984)	2,094	1,615	3,709	Canada	12.37	8.73	12.37	8.73							The four items for handedness from the Lateral Preference Inventory by Coren	
Searleman, Tweedy, and Springer (1979)	319	528	847	U.S.	13.79	13.26			13.79	13.26	3.45	2.84			14-item modified Crovitz & Zener handedness index	
Segal (1984)	931	646	1,577	U.S.	9.99	8.98	9.99	8.98							Writing hand	
Shan-Ming et al. (1985)	102	99	201	China	8.82	4.04							8.82	4.04	10-item preference demonstration	The participants were controls to individuals with schizophrenia.
	98	133	231		8.16	6.77							8.16	6.77		
Sherman (1979)	55	43	98	U.S.	49.09	23.26							49.09	23.26	14-item Crovitz & Zener questionnaire	

Table 1 (*continued*)

Study	*N* (men)	*N* (women)	*N* (total)	Geographical location	% Left-handedness (total)		% Left-handedness forced choice		% Left-handedness stringent		% Mixed-handedness		% Nonright-handedness		Measure of handedness	Notes
					M	F	M	F	M	F	M	F	M	F		
Shettel-Neuber and O'Reilly (1983)	109	109	218	U.S.	3.67	4.59			3.67	4.59	3.67	2.75			Filial report	Data were also reported on the faculty members, but not broken down by sex.
Shimizu and Endo (1983)	2,159	2,123	4,282	Japan	4.03	2.36			4.03	2.36	4.59	3.39			13-item questionnaire	
Singh and Bryden (1994)	278	451	729	India	10.79	6.87	10.79	6.87							The first factor from the 59-item version of the Waterloo Handedness Questionnaire (10-items)	
Smith (1987)	164	186	350	U.K.	10.98	6.99	10.98	6.99							10-item EHI	The participants were controls to allergic patients, matched for age and sex.
Spiegler and Yeni-Komshian (1983)	810	1,006	1,816	U.S.	15.19	12.62	15.19	12.62							Writing hand	
	1,816	1,816	3,632		10.19	8.20	10.19	8.20								
Stoyanov, Nikolova, and Pashalieva (2011)	1,530	1,652	3,182	Bulgaria	13.66	8.96							13.66	8.96	Annett Hand Preference Questionnaire, EHI	
Suar, Mandal, Misra, and Suman (2013)	2,822	876	3,698	India	4.15	3.42	4.15	3.42							13-item handedness questionnaire, writing hand (1 of the 13)	Writing hand was taken into account for the meta-analysis. Even though the age range was 9–83 years, the study was included because the majority of the participants was within our age criterion (mean age for men 30,18 *SD* = 16,57)
Tan (1986)	173	93	266	Turkey	7.51	0.00			7.51	0.00	31.79	24.73			12-item Annett Handedness questionnaire	
Tan (1988)	750	350	1,100	Turkey	3.07	4.00			3.07	4.00	32.80	26.00			Turkish adaptation of the EHI	
Tapley and Bryden (1985)	687	824	1,511	Canada	11.50	9.71	11.50	9.71							Eight-item questionnaire	
Teng, Lee, Yang, and Chang (1979)	1,025	1,016	2,041	Taiwan	5.95	2.95	5.95	2.95							12-item EHI	Another 2,102 subjects were tested, but their mean age was 11 years, so they were excluded. The percentages of handedness though, have been calculated for the whole sample, but no significant differences were reported between the school and university sample.
Thompson and Marsh (1976)	669	630	1,299	U.S.	5.53	3.17			5.53	3.17	35.72	29.52			Four-item questionnaire	
Tonetti, Adan, Caci, Fabbri, and Natale (2012)	1,353	2,120	3,473	Spain, Italy, France	11.53	7.88	11.53	7.88							EHI	
Tran, Stieger, and Voracek (2014)	5,515	7,205	12,720	Austria, Germany	8.83	7.48			8.83	7.48	2.47	2.23			12-item handedness questionnaire	Two data sets (discovery and replication sample) were combined.
Tsuang, Chen, Kuo, and Hsiao (2016)	1,597	1,848	3,445	Taiwan	5.32	3.63	5.32	3.63							Annett Hand Preference Questionnaire (Briggs and Nebes, 1975), writing hand	Writing hand was taken into account for the meta-analysis.
Walker and Henneberg (2007)	8	13	21	Australia	0.00	15.38			0.00	15.38	25.00	7.69			EHI	There were seven handedness groups. The intermediate classes were grouped to form the mixed-handedness class for the purposes of the meta-analysis.
Wolf, D'Agostino, and Cobb (1991)	869	1,219	2,088	U.S.	9.78	8.45	9.78	8.45							Interview	
Wood and Aggleton (1989)	500	252	752	U.K.	12.20	11.90			12.20	11.90	2.00	3.97			Hand used to hold a racket	
Wood and Aggleton (1991)	842	398	1,240	U.K.	11.21	6.61	11.21	6.61							10-item EHI	

(*table continues*)

Table 1 (*continued*)

Study	*N* (men)	*N* (women)	*N* (total)	Geographical location	% Left-handedness (total)		% Left-handedness forced choice		% Left-handedness stringent		% Mixed-handedness		% Nonright-handedness		Measure of handedness	Notes
					M	F	M	F	M	F	M	F	M	F		
Xu and Zheng (2017)	392	554	946	China	6.12	4.87			6.12	4.87	11.22	10.65			Writing hand	The subgroup that was selected was that of the heterosexual individuals according to sexual attraction, not sexual behavior or identity.
You et al. (2015)	21	19	40	Korea	23.81	26.32									Self-classification	Calculations based on raw data kindly provided by the authors.
Yule, Brotto, and Gorzalka (2014)	190	500	690	52% European, 32% East Asian, 16% other	13.16	12.00							13.16	12.00	EHI	The numbers of the handedness groups were calculated based on the percentages given.
Zhu et al. (2009)	9,234	9,234	18,468	Denmark	7.94	6.92			7.94	6.92	4.53	2.79			Self-report ("Which hand do you use the most?")	Strong dextrals and dextrals were considered to be one class, the right-handers, for the purposes of the meta-analysis. Also, strong sinistrals and sinistrals were grouped to form the left-handedness class. Two studies (Aalborg-Odense Birth Cohort study and Aarhus Birth Cohort study) were combined.

Note. BDI = Beck Depression Inventory.

Table 2
Incidence of Left-Handedness in the Different Levels of the Moderator Variables Within the Left-Handedness (Total) Comparison

Variable	Levels	Datasets (*N*)	Participants (*N*)	Men (*N*)	Women (*N*)	Left- handedness (total) (%)
Classification	R-L	170	411,992	212,788	199,204	10.16% (95% CI [9.10%, 11.20%])
	R-M-L	70	787,999	376,190	411,809	9.49% (95% CI [7.93%, 11.00%])
	R-nonR	22	1,196,179	523,387	672,792	16.57% (95% CI [12.85%, 20.30%])
Instrument	Annett's Hand Preference Questionnaire (8-, 10-, 12-, 23-items)	6	4,770	2,349	2,421	12.63% (95% CI [4.29%, 21.00%])
	Edinburgh Handedness Inventory (10-items)	47	65,686	31,422	34,264	13.51% (95% CI [10.29%, 16.70%])
	Writing hand	71	436,921	232,855	204,066	9.29% (95% CI [8.45%, 10.10%])
	Self-classification ('Are you right-, (mixed-), or left-handed?')	29	575,588	263,722	311,866	9.24% (95% CI [8.07%, 10.40%])
	Briggs & Nebes Questionnaire	6	5,562	2,972	2,590	9.73% (95% CI [8.23%, 11.20%])
	Four items on handedness from Coren and Porac's Laterality Inventory	9	18,210	8,620	9,590	9.75% (95% CI [8.95%, 10.50%])
	Observation	15				15.11% (95% CI [9.15%, 21.10%])
Number of questionnaire items	1	118	1,024,509	504,192	520,317	9.66% (95% CI [8.84%, 10.50%])
	2–9	31	1,218,679	536,505	682,174	10.15% (95% CI [8.23%, 12.10%])
	10–15	87	116,467	56,000	60,467	11.93% (95% CI [9.1%, 14.10%])
	>15	7	6,336	2,234	4,102	12.82% (95% CI [4.00%, 21.60%])
Response format	R-L	44	1,376,363	620,670	755,693	9.83% (95% CI [8.05%, 11.60%])
	R-M-L	79	639,165	294,623	344,542	10.34% (95% CI [9.01%, 11.70%])
	5-point scale	40	218,262	117,564	100,698	11.26% (95% CI [8.07%, 14.40%])
	+ or ++	10	29,814	13,529	16,285	10.50% (95% CI [5.98%, 15.00%])
Main purpose of the study to measure handedness	Yes	161	2,123,344	965,955	1,157,389	10.10% (95% CI [8.88%, 11.30%])
	No	100	270,798	145,304	125,494	11.40% (95% CI [10.11%, 12.70%])
Year of publication	<1976	18	27,568	14,346	13,222	7.19% (95% CI [5.62%, 8.76%])
	1976–1985	69	76,287	37,747	38,540	10.73% (95% CI [8.81%, 12.65%])
	1986–1995	70	1,302,927	573,093	729,834	10.64% (95% CI [8.90%, 12.38%])
	1996–2007	46	381,594	206,743	174,851	11.70% (95% CI [9.57%, 13.82%])
	2008–2019	57	607,487	280,259	327,228	10.77% (95% CI [8.62%, 12.92%])
Report	Self-report	232	2,329,356	1,078,002	1,251,354	10.50% (95% CI [9.58%, 11.40%])
	Not self-report	28	55,263	28,597	26,666	11.90% (95% CI [8.22%, 15.60%])
Ancestry	European	184	1,738,827	808,191	930,636	11.12% (95% CI [10.09%, 12.15%])
	Sub-Sahara African	9	4,645	2,338	2,307	7.71% (95% CI [6.25%, 9.18%])
	East Asian	23	29,044	14,622	14,422	5.69% (95% CI [3.49%, 7.88%])
Sporting elite	Yes	12	9,301	5,755	3,546	14.70% (95% CI [9.72%, 19.80%])
	No	250	2,386,869	1,106,610	1,280,259	10.40% (95% CI [9.52%, 11.30%])
Education	High	101	94,661	44,166	50,495	11.40% (95% CI [9.86%, 12.90%])
	Average	142	2,256,509	1,045,055	1,211,454	10.10% (95% CI [8.92%, 11.30%])

Table 3
Overall Incidence of Left-Handedness in the Data Sets

Comparison	Number of data sets	Number of participants	Number of men	Number of women	Overall incidence (%, [95% CI])
Left-handedness (stringent)	72	789,090	376,844	412,246	9.34% (95% CI [7.92%, 10.80%])
Left-handedness (forced choice)	173	413,560	213,494	200,066	10.20% (95% CI [9.14%, 11.20%])
Nonright-handedness	26	1,203,403	526,622	676,781	18.10% (95% CI [13.90%, 22.30%])
Mixed-handedness	72	789,090	376,844	412,246	9.33% (95% CI [6.67%, 12.00%])
Left-handedness (total)	262	2,396,170	1,112,365	1,283,805	10.60% (95% CI [9.71%, 11.50%])

prevalence rates for each level of the moderator variables in Table 4.

Overall Effect Estimates

Meta-analysis 1: Left-handedness (total). A total of $k = 262$ data sets (from 200 studies) were included in the analysis, totaling $n = 2,396,170$ individuals. Simple meta-analysis using robumeta gave an estimate of the left-handedness (total) prevalence of 10.60%, with a 95% CI between 9.71 and 11.50% (see online Supplementary Material Figure 1). Heterogeneity among the data sets was found to be high ($I^2 = 97.42\%$, $\tau^2 = 5.31$). For women, the point estimate was 9.53%, 95% CI [8.75%, 10.30%]. For men, the point estimate was 11.62%, 95% CI [10.66%, 12.60%]. There was clear evidence that left-handedness (total) prevalence was higher in men than in women (2.09%, $SE = 0.24\%$, 95% CI [1.61%, 2.57%], $t(198) = 8.59$, $p < .001$; see Figure 2A).

Egger's regression test for funnel plot asymmetry revealed clear evidence for small study bias ($z = -4.24$, $p < .001$), as did the visual inspection of the funnel plot (see Figure 2B). According to the trim and fill test, 53 studies ($SE = 10.60$) will need to be imputed to the right of the mean, corresponding to higher left-handedness (total) rates for the funnel plot to be symmetrical (the two unpublished data sets by Dane were not included in this analysis).

Meta-analysis 2: Nonright-handedness. A total of $k = 26$ data sets (from 24 studies) were included in the analysis, totaling $n = 1,203,403$ individuals. Simple meta-analysis using robumeta gave an estimate of the nonright-handedness prevalence of 18.10% with a 95% CI [13.90%, 22.30%]. Heterogeneity among the data sets was found to be high ($I^2 = 99.56\%$, $\tau^2 = 83.29$). For women, the point estimate was 16.20%, 95% CI [12.00%, 20.30%]. For men, the point estimate was 19.80%, 95% CI [15.10%, 24.60%]. There was evidence that nonright-handedness prevalence was higher in men than in women (3.66%, $SE = 1.46\%$, 95% CI [0.63%, 6.69%], $t(22) = 2.50$, $p < .05$; see Figure 2C).

Egger's regression test for funnel plot asymmetry revealed no evidence for small study bias ($z = -1.15$, $p = .252$), although visual inspection of the funnel plot indicated asymmetry (see Figure 2D). According to the trim and fill test, seven studies ($SE = 3.37$) will need to be imputed to the left of the mean, corresponding to lower nonright-handedness rates, for the funnel plot to be symmetrical.

Meta-analysis 3: Left-handedness (forced choice). A total of $k = 173$ data sets (from 123 studies) were included in the analysis, totaling $n = 413,560$ individuals. Simple meta-analysis using robumeta gave an estimate of the left-handedness (forced choice) prevalence of 10.20% with a 95% CI [9.14%, 11.20%]. Heterogeneity among the data sets was found to be high ($I^2 = 96.52\%$, $\tau^2 = 16.28$). For women, the point estimate was 9.15%, 95% CI [8.16%, 10.10%]. For men, the point estimate was 11.50%, 95% CI [10.24%, 12.80%]. There was clear evidence that left-handedness (forced choice) prevalence differed between men and women (2.35%, $SE = 0.37\%$, 95% CI [1.61%, 3.09%], $t(121) = 6.30$, $p < .001$; see Figure 2E).

Egger's regression test for funnel plot asymmetry revealed clear evidence for small study bias ($z = -2.96$, $p < .01$), as did the visual inspection of the funnel plot (see Figure 2F). According to the trim and fill test, 27 studies ($SE = 8.59$) will need to be imputed to the right of the mean, corresponding to higher left-handedness (forced choice) rates for the funnel plot to be symmetrical. (The two unpublished data sets by Dane were not included in this analysis.)

Meta-analysis 4: Left-handedness (stringent). A total of $k = 72$ data sets (from 63 studies) were included in the analysis, totaling $n = 789,090$ individuals. Simple meta-analysis using robumeta gave an estimate of the left-handedness (stringent) prevalence of 9.34% with a 95% CI [7.92%, 10.80%]. Heterogeneity among the data sets was found to be high ($I^2 = 97.07\%$, $\tau^2 = 5.57$). For women, the point estimate was 8.88%, 95% CI [7.43%, 10.30%]. For men, the point estimate was 9.74%, 95% CI [8.45%, 11.00%]. There was evidence that left-handedness (stringent) prevalence differed between men and women (0.86%, $SE = 0.30\%$, 95% CI [0.27%, 1.45%], $t(61) = 2.90$, $p < .01$; see Figure 2G).

Egger's regression test for funnel plot asymmetry revealed evidence for small study bias ($z = -2.48$, $p < .05$), as did visual inspection of the funnel plot (see Figure 2H). According to the trim and fill test, 18 studies ($SE = 5.56$) will need to be imputed to the right of the mean, corresponding to higher left-handedness (stringent) rates for the funnel plot to be symmetrical.

Meta-analysis 5: Mixed-handedness. A total of $k = 72$ data sets (from 63 studies) were included in the analysis, totaling $n = 789,090$ individuals. Simple meta-analysis using robumeta gave an estimate of the mixed-handedness prevalence of 9.33% with a 95% CI [6.67%, 12.00%]. Heterogeneity among the data sets was found to be high ($I^2 = 99.32\%$, $\tau^2 = 95.45$). For women, the point estimate was 8.53%, 95% CI [6.01%, 11.00%]. For men, the point estimate was 10.84%, 95% CI [7.78%, 13.90%]. There was clear evidence that mixed-handedness prevalence differed between men and women (2.31%, $SE = 0.45\%$, 95% CI [1.42%, 3.20%], $t(61) = 5.18$, $p < .001$; see Figure 2I).

Egger's regression test for funnel plot asymmetry revealed clear evidence for small study bias ($z = -3.56$, $p < .001$), as did visual inspection of the funnel plot (see Figure 2J). However, according to the trim and fill test, no studies needed to be "trimmed" or "filled."

Table 4
Moderator Variables Extracted From Each Study

Study	Total (*N*)	Educational status	Ancestry	Classification of handedness	Instrument of handedness	Length of questionnaire (number of items)	Response format	Main purpose of the study	Report	Sport elite
Aggleton et al. (1994)	1,538	General population	European	R-L	Writing hand	1	n/a	Handedness	Self-report	No
Aggleton and Wood (1990)	344	General population	European	R-L	Observation of an action/ official records	1	R-M-L	Other	No self-report	Yes
	363	College students		R-M-L	n/a	1	R-M-L	Other	Self-report	No
Anakwe et al. (2007)	250	General population	European	R-L	Self-classification	1	n/a	Other	Self-report	No
Annett (1973)	3,644	College students	European	R-L	Writing hand	1	n/a	Handedness	Self-report	No
	7,288	General population		R-L	Writing hand	1	n/a	Handedness	n/a	No
Annett (1979)	804	College students	European	R-L	Writing hand	1	R-L	Handedness	Self-report	No
	690	General population		R-L	Writing hand	1	R-L	Handedness	No self-report	No
	1,540	General population		R-L	Writing hand	1	R-L	Handedness	No self-report	No
Annett (1985)	642	General population	n/a	R-L	n/a	n/a	n/a	Handedness	Self-report	No
	747	General population	n/a	R-L	n/a	n/a	n/a	Handedness	Self-report	No
	224	General population	n/a	R-L	Observation of an action/ official records	1	n/a	Other	No self-report	Yes
	66	General population	n/a	R-L	Observation of an action/ official records	1	n/a	Other	No self-report	Yes
Annett (2002)	200	General population	n/a	R-L	Observation of an action/ official records	1	n/a	Other	No self-report	Yes
Annett (2008)	578	General population	European	R-L	Writing hand	1	n/a	Handedness	Self-report	No
	1,670	College students		R-L	Writing hand	1	n/a	Handedness	Self-report	No
	3,364	General population		R-L	Writing hand	1	n/a	Handedness	No self-report	No
Annett and Kilshaw (1982)	1,550	College students	European	R-L	Writing hand	1	n/a	Other	Self-report	No
Ardila and Rosselli (2001)	6,941	General population	n/a	R-M-L	Self-classification	1	R-M-L	Handedness	Self-report	No
Arning et al. (2015)	1,056	General population	European	R-M-L	EHI	10	R-L	Handedness	Self-report	No
Ashton (1982)	2,027	General population	European	R-L	Writing hand	1	R-L	Handedness	Self-report	No
	840	General population	East Asian	R-L	Writing hand	1	R-L	Handedness	Self-report	No
	758	General population	n/a	R-L	Writing hand	1	R-L	Handedness	Self-report	No
Azémar and Stein (1994)	2,490	General population	n/a	R-L	Observation of an action/ official records	1	n/a	Handedness	No self-report	Yes
Bakan and Putnam (1974)	400	College students	European	R-L	Writing hand	1	n/a	Other	Self-report	No
Barut et al. (2007)	633	n/a	n/a	R-M-L	EHI	10	+ or ++ under R-L columns	Other	Self-report	No
Beckman and Elston (1962)	981	General population	European	R-L	n/a	n/a	n/a	Handedness	Self-report	No
Betancur, Vélez, Cabanieu, LeMoal, and Neveu (1990)	205	General population	European	R-M-L	n/a	10	5-point scale	Other	Self-report	No
Birkett (1981)	125	General population	European	R-L	EHI	10	n/a	Handedness	Self-report	No
Briggs and Nebes (1975)	1,599	College students	European	R-M-L	Briggs & Nebes	12	5-point scale	Handedness	Self-report	No
Brito et al. (1989)	959	College students	n/a	R-M-L	EHI	10	R-M-L	Handedness	Self-report	No
Bryden (1977)	1,106	College students	European	R-L	Writing hand	1	5-point scale	Handedness	Self-report	No
Bryden (1989)	794	College students	European	R-L	n/a	8	n/a	Other	Self-report	No
Bryden and Roy (2005)	153	College students	European	R-L	Writing hand	1	n/a	Other	Self-report	No
Buchtel and Rueckert (1984)	740	College students	European	R-L	Writing hand	1	R-L	Other	Self-report	No
Cannon et al. (1995)	43	General population	European	R-M-L	EHI	10	n/a	Handedness	Self-report	No
Carrière and Raymond (2000)	246	General population	sub-Sahara African	R-L	Observation of an action/ official records	1	R-L	Other	No self-report	No
Casey and Brabeck (1989)	433	College students	European	R-nonR	EHI	10	+ or ++ under R-L columns	Other	Self-report	No
Chamberlain (1928)	4,354	General population	European	R-L	Writing hand	1	R-L	Handedness	No self-report	No
Chapman and Walsh (1973)	923	n/a	European	R-M-L	Observation of an action/ official records	1	R-M-L	Handedness	Self-report	No
Chapman and Chapman (1987)	5,825	College students	European	R-M-L	n/a	13	R-M-L	Handedness	Self-report	No
Chen et al. (2007)	411	General population	European	R-L	EHI	10	n/a	Other	Self-report	No
Chisnall (2010)	302	General population	European	R-M-L	Writing hand	1	n/a	Handedness	Self-report	No

(*table continues*)

Table 4 (*continued*)

Study	Total (*N*)	Educational status	Ancestry	Classification of handedness	Instrument of handedness	Length of questionnaire (number of items)	Response format	Main purpose of the study	Report	Sport elite
Çiçek, Arabaci, and Canakçi (2010)	1,510	General population	n/a	R-L	EHI	10	n/a	Handedness	Self-report	No
Coren (1989)	1,896	College students	European	R-L	Four items from Porac & Coren Laterality Inventory	4	n/a	Other	Self-report	No
Coren (1993)	3,307	College students	European	R-L	Four items from Porac & Coren Laterality Inventory	4	R-M-L	Handedness	Self-report	No
Coren (1995)	2,596	General population	European	R-L	Four items from Porac & Coren Laterality Inventory	n/a	R-M-L	Other	No self-report	No
Coren and Porac (1979)	1,758	General population	European	R-L	Writing hand	1	R-L	Handedness	Self-report	No
Coren and Porac (1980)	2,761	General population	European	R-L	Four items from Porac & Coren Laterality Inventory	4	R-M-L	Other	Self-report	No
	1,410	General population		R-L	Four items from Porac & Coren Laterality Inventory	4	R-M-L	Other	Self-report	No
Coren et al. (1986)	1,180	College students	European	R-L	Four items from Porac & Coren Laterality Inventory	4	R-M-L	Other	Self-report	No
Cornell and McManus (1992)	266	College students	European	R-L	Writing hand	1	n/a	Handedness	Self-report	No
Cosenza and Mingoti (1993)	1,961	College students	n/a	R-L	EHI	10	+ or ++ under R-L columns	Other	Self-report	No
	14,629	General population		R-L	EHI	10	+ or ++ under R-L columns	Other	Self-report	No
Cosenza and Mingoti (1995)	15,389	General population	n/a	R-L	EHI	n/a	n/a	Other	Self-report	No
Cuff (1931)	109	College students	European	R-L	n/a	8	R-L	Handedness	Self-report	No
Curt et al. (1995)	1,609	General population	European	R-L	n/a	12	R-M-L	Handedness	Self-report	No
Dane and Erzurumluoğlu (2003)	326	General population	n/a	R-L	EHI	10	R-M-L	Other	Self-report	Yes
Dane (2019)	107	College students	sub-Sahara African	R-L	EHI	10	n/a	Handedness	Self-report	No
	200	General population	sub-Sahara African	R-L	EHI	10	n/a	Handedness	Self-report	No
Dane et al. (2009)	118	General population	n/a	R-M-L	EHI	10	n/a	Handedness	Self-report	No
Dargent-Paré, De Agostini, Meshbah, M., and Dellatolas (1992)	652	n/a	n/a	R-L	n/a	12	R-M-L	Other	Self-report	No
	685	n/a	European	R-L	n/a	12	R-M-L	Other	Self-report	No
	701	n/a	European	R-L	n/a	12	R-M-L	Other	Self-report	No
	725	n/a	European	R-L	n/a	12	R-M-L	Other	Self-report	No
	2,301	n/a	European	R-L	n/a	12	R-M-L	Other	Self-report	No
De Agostini et al. (1997)	764	General population	sub-Sahara African	R-L	n/a	1	R-M-L	Handedness	No self-report	No
	755	College students		R-L	n/a	10	5-point scale	Handedness	Self-report	No
	1,470	General population		R-L	n/a	1	R-M-L	Handedness	No self-report	No
de Kovel, Carrión-Castillo, and Francks (2019)	501,447	General population	n/a	R-M-L	Self-classification	1	R-M-L	Handedness	Self-report	No
de la Fuente, Casasanto, Román, and Santiago (2015)	94	College students	n/a	R-L	EHI	10	n/a	Handedness	Self-report	No
	71	College students	European	R-L	EHI	10	n/a	Handedness	Self-report	No
	29	College students	European	R-L	Writing hand	1	n/a	Handedness	Self-report	No
	40	College students	n/a	R-L	n/a	4	n/a	Handedness	Self-report	No
DeLisi et al. (2002)	288	general population	European	R-M-L	Annett's	25	n/a	Handedness	Self-report	No
Demura et al. (2006)	3,557	general population	East Asian	R-M-L	EHI	10	R-M-L	Other	Self-report	No
Dinsdale et al. (2011)	395	College students	European	R-M-L	Writing hand	1	+ or ++ under R-L columns	Handedness	Self-report	No
Dirnberger (2012)	1,015	College students	European	R-L	EHI	10	5-point scale	Handedness	Self-report	No
Downey (1927)	721	n/a	European	R-L	n/a	**5**	n/a	Handedness	Self-report	No
Dragovic et al. (2008)	787	General population	European	R-L	Writing hand	1	n/a	Handedness	Self-report	No
Dronamraju (1975)	431	General population	n/a	R-L	Observation of an action/ official records	1	R-L	Handedness	No self-report	No

Table 4 (*continued*)

Study	Total (*N*)	Educational status	Ancestry	Classification of handedness	Instrument of handedness	Length of questionnaire (number of items)	Response format	Main purpose of the study	Report	Sport elite
	86	General population		R-L	Observation of an action/ official records	1	R-L	Handedness	No self-report	No
Elalmiş and Tan (2005)	22,461	n/a	n/a	R-M-L	Self-classification	1	R-M-L	Handedness	Self-report	No
Elalmis and Tan (2008)	197	College students	n/a	R-L	Writing hand	1	R-L	Handedness	Self-report	No
Elias et al. (2001)	541	College students	European	R-L	Self-classification	1	n/a	Other	Self-report	No
Ellis et al. (1988)	6,577	General population	European	R-L	EHI	10	+ or ++ under R-L columns	Handedness	Self-report	No
Elneel et al. (2008)	52	College students	European	R-M-L	n/a	7	R-M-L	Handedness	Self-report	No
Espírito-Santo et al. (2017)	342	General population	European	R-M-L	EHI	10	+ or ++ under R-L columns	Handedness	Self-report	No
Fagard et al. (2015)	704	General population	European	R-M-L	n/a	15	R-M-L	Handedness	Self-report	No
Faurie et al. (2008)	11,895	General population	European	R-L	Self-classification	1	R-L	Handedness	Self-report	No
	13,954	General population	European	R-L	n/a	6	n/a	Other	Self-report	No
Fry (1990)	366	College students	European	R-L	EHI	10	n/a	Other	No self-report	No
	721	General population		R-L	Writing hand	1	n/a	Other	No self-report	No
Genetta-Wadley and Swirsky-Sacchetti (1990)	60	College students	European	R-L	Annett's	12	n/a	Other	Self-report	No
Gilbert and Wysocki (1992)	1,177,507	General population	European	R-nonR	n/a	2	R-L	Handedness	Self-report	No
Gladue and Bailey (1995)	149	General population	European	R-nonR	Annett's	10	5-point scale	Other	Self-report	No
Götestam (1990)	60	College students	European	R-M-L	Writing hand	1	R-M-L	Handedness	Self-report	No
	175	College students		R-M-L	Writing hand	1	R-M-L	Handedness	Self-report	No
Green and Young (2001)	284	College students	European	R-M-L	n/a	6	R-M-L	Handedness	Self-report	No
Grouios et al. (2000)	1,112	General population	European	R-L	Briggs & Nebes	12	5-point scale	Other	Self-report	Yes
	1,187	College students	European	R-L	Briggs & Nebes	12	5-point scale	Other	Self-report	No
Gunstad et al. (2007)	643	General population	n/a	R-nonR	EHI	10	n/a	Other	Self-report	No
Gupta et al. (2008)	84	College students	n/a	R-L	Self-classification	1	n/a	Handedness	Self-report	No
Gur and Gur (1977)	200	General population	European	R-L	n/a	23	R-L	Other	Self-report	No
Halpern et al. (1998)	152,653	General population	European	R-L	Writing hand	1	R-L	Other	Self-report	No
Hannay et al. (1990)	1,185	College students	European	R-M-L	n/a	10	n/a	Other	Self-report	No
Hannula et al. (2012)	850	General population	European	R-L	Self-classification	1	R-L	Other	Self-report	No
Harburg et al. (1978)	735	General population	European	R-L	Self-classification	1	R-L	Other	Self-report	No
	761	General population	sub-Sahara African	R-L	Self-classification	1	R-L	Other	Self-report	No
Harburg et al. (1981)	651	General population	European	R-L	Writing hand	1	R-L	Other	Self-report	No
	502	General population		R-L	Writing hand	1	R-L	Other	Self-report	No
Harris and Gitterman (1978)	356	College students	European	R-L	Briggs & Nebes	12	5-point scale	Other	Self-report	No
Harvey (1988)	398	College students	European	R-L	EHI	10	R-M-L	Other	Self-report	No
Hatta and Kawakami (1995)	1,700	College students	East Asian	R-M-L	n/a	10	n/a	Handedness	Self-report	No
Hatta and Nakatsuka (1976)	1,199	General population	East Asian	R-L	n/a	10	R-M-L	Handedness	Self-report	No
Heim and Watts (1976)	398	College students	European	R-L	Writing hand	1	R-L	Other	Self-report	No
	492	College students		R-L	Writing hand	1	R-L	Other	Self-report	No
Heikkilä et al. (2015)	1,791	General population	European	R-L	Writing hand	1	R-L	Handedness	Self-report	No
Hicks et al. (1980)	580	College students	European	R-L	Briggs & Nebes	12	n/a	Other	Self-report	No
Hicks and Kinsbourne (1976)	2,202	General population	European	R-L	Writing hand	1	R-L	Handedness	No self-report	No
Hicks et al. (1978)	728	College students	European	R-L	Briggs & Nebes	12	5-point scale	Other	Self-report	No
Holder (1992)	314	College students	European	R-M-L	Self-classification	1	R-M-L	Handedness	Self-report	No
Holtzen (1994)	260	General population	European	R-M-L	n/a	5	5-point scale	Other	Self-report	No
Holtzen (2000)	1,685	General population	n/a	R-L	Observation of an action/ official records	1	R-L	Other	No self-report	Yes
Hoogmartens and Caubergh (1987)	128	n/a	European	R-L	Four items from Porac & Coren Laterality Inventory	4	R-M-L	Other	Self-report	No
Hoosain (1990)	556	College students	East Asian	R-M-L	n/a	10	R-M-L	Handedness	Self-report	No
Huang and Sejdić (2013)	20	general population	European	R-M-L	EHI	10	n/a	Other	Self-report	No
Ida and Bryden (1996)	655	College students	East Asian	R-L	Writing hand	1	5-point scale	Handedness	Self-report	No
	620	College students	European	R-L	Writing hand	1	5-point scale	Handedness	Self-report	No

(*table continues*)

Table 4 (*continued*)

Study	Total (*N*)	Educational status	Ancestry	Classification of handedness	Instrument of handedness	Length of questionnaire (number of items)	Response format	Main purpose of the study	Report	Sport elite
Inglis and Lawson (1984)	1,880	General population	European	R-L	n/a	3	n/a	Other	Self-report	No
Iwasaki et al. (1995)	1,755	General population	East Asian	R-L	Writing hand	15	R-M-L	Handedness	Self-report	No
Jung and Jung (2009)	1,885	General population	East Asian	R-M-L	n/a	13	n/a	Handedness	Self-report	No
Kalaycıoğlu, Kara, Atbaşoğlu, and Nalçacı (2008)	49	College students	n/a	R-nonR	n/a	13	R-M-L	Handedness	Self-report	No
Kalichman, Korostishevsky, and Kobyliansky (2008)	1,187	General population	European	R-L	Writing hand	1	n/a	Handedness	Self-report	No
Kauranen and Vanharanta (1996)	40	General population	European	R-L	Self-classification	1	n/a	Handedness	Self-report	No
	40	General population		R-L	Self-classification	1	n/a	Handedness	Self-report	No
	40	General population		R-L	Self-classification	1	n/a	Handedness	Self-report	No
	40	General population		R-L	Self-classification	1	n/a	Handedness	Self-report	No
	40	General population		R-L	Self-classification	1	n/a	Handedness	Self-report	No
Klum et al. (2012)	750	General population	European	R-L	Self-classification	1	n/a	Handedness	Self-report	No
Kuderer and Kirchengast (2016)	55	College students	European	R-M-L	Observation of an action/ official records	22	R-L	Handedness	No self-report	No
Lai et al. (2014)	1,023	General population	European	R-M-L	Writing hand	1	R-M-L	Handedness	Self-report	No
Lambert and Hallett (2009)	886	General population	European	R-M-L	Writing hand	1	R-M-L	Handedness	Self-report	No
Lansky et al. (1988)	888	General population	European	R-L	Writing hand	1	R-M-L	Handedness	Self-report	No
	853	General population	European	R-L	Writing hand	1	R-M-L	Handedness	Self-report	No
	185	General population	sub-Sahara African	R-L	Writing hand	1	R-M-L	Handedness	Self-report	No
	157	General population	sub-Sahara African	R-L	Writing hand	1	R-M-L	Handedness	Self-report	No
Lee-Feldstein and Harburg (1982)	1,153	General population	European	R-L	Writing hand	1	R-L	Other	Self-report	No
Leiber and Axelrod (1981)	1,766	College students	European	R-M-L	Self-classification	1	R-M-L	Handedness	Self-report	No
	711	College students		R-M-L	Self-classification	1	R-M-L	Handedness	Self-report	No
Lester, Werling, and Heinle (1982)	2,168	n/a	European	R-L	n/a	n/a	n/a	Other	Self-report	No
Levander and Schalling (1988)	921	College students	European	R-M-L	Writing hand	1	5-point scale	Handedness	Self-report	No
Lien et al. (2015)	626	College students	East Asian	R-L	Writing hand	1	5-point scale	Handedness	Self-report	No
	1,314	General population	East Asian	R-L	Writing hand	1	5-point scale	Handedness	Self-report	No
Lippa (2003)	1,056	n/a	European	R-M-L	n/a	1	5-point scale	Other	Self-report	No
Loffing et al. (2014)	903	College students	European	R-L	EHI	10	5-point scale	Handedness	Self-report	No
Loffing (2017)	1,485	General population	n/a	R-L	Observation of an action/ official records	1	n/a	Handedness	No self-report	Yes
Lui et al. (2012)	62	College students	European	R-L	n/a	n/a	5-point scale	Handedness	Self-report	No
Lyle et al. (2013)	163	College students	European	R-L	EHI	10	5-point scale	Handedness	Self-report	No
Maehara et al. (1988)	2,459	n/a	East Asian	R-nonR	EHI	10	R-M-L	Handedness	Self-report	No
Marchant-Haycox et al. (1991)	396	General population	European	R-L	n/a	n/a	5-point scale	Other	Self-report	No
Marmolejo-Ramos et al. (2017)	1,160	College students	n/a	R-L	Self-classification	1	n/a	Other	Self-report	No
Martin and Porac (2007)	1,635	General population	n/a	R-L	Self-classification	1	5-point scale	Handedness	Self-report	No
Mascie-Taylor et al. (1981)	141	General population	European	R-L	Writing hand	1	R-L	Other	Self-report	No
Mascie-Taylor (1980)	386	General population	European	R-L	Writing hand	1	R-L	Other	Self-report	No
McFarland and Anderson (1980)	181	College students	European	R-L	Writing hand	1	5-point scale	Handedness	Self-report	No
McGee (1976)	112	College students	European	R-L	n/a	7	n/a	Other	Self-report	No
McGee and Cozad (1980)	1,230	College students	European	R-nonR	EHI	10	n/a	Handedness	Self-report	No
McKeever and Riche (1990)	3,080	College students	European	R-L	Writing hand	10	n/a	Other	Self-report	No
McManus (1986)	2,028	General population	European	R-L	Self-classification	1	R-L	n/a	Self-report	No
Merrell (1957)	123	General population	European	R-L	Writing hand	1	n/a	Handedness	Self-report	No
	497	General population		R-L	Writing hand	1	n/a	Handedness	No self-report	No
Mészáros et al. (2006)	150	General population	European	R-L	n/a	n/a	n/a	Other	Self-report	No
Milenković et al. (2013)	1,202	General population	European	R-L	Writing hand	1	n/a	Handedness	Self-report	No
Morley and Caffrey (1994)	3,814	General population	European	R-M-L	Writing hand	1	R-M-L	Other	Self-report	No
Mustanski et al. (2002)	382	College students	European	R-M-L	Self-classification	1	R-M-L	Other	Self-report	No
Nalçaci, Kalaycioğlu, Çiçek, and Genç (2001)	310	College students	n/a	R-nonR	n/a	13	R-M-L	Other	Self-report	No
Narr et al. (2007)	67	General population	European	R-nonR	EHI	20	R-M-L	Handedness	Self-report	No
Newcombe and Ratcliff (1973)	823	General population	European	R-M-L	n/a	7	n/a	Other	Self-report	No

Table 4 (*continued*)

Study	Total (*N*)	Educational status	Ancestry	Classification of handedness	Instrument of handedness	Length of questionnaire (number of items)	Response format	Main purpose of the study	Report	Sport elite
Newcombe et al. (1975)	928	General population	European	R-M-L	n/a	7	R-L	Other	Self-report	No
Nicholls, Orr, Yates, and Loftus (2008)	600	College students	European	R-nonR	n/a	n/a	n/a	Handedness	Self-report	No
Nicholls et al. (2010)	825	General population	n/a	R-L	Annett's	12	n/a	Handedness	Self-report	No
Nicholls et al. (2013)	3,324	College students	n/a	R-M-L	n/a	31	R-M-L	Handedness	Self-report	No
Obrzut et al. (1992)	318	College students	European	R-L	n/a	14	n/a	Handedness	Self-report	No
Ocklenburg et al. (2016)	206	General population	European	R-L	EHI	10	n/a	Other	Self-report	No
	103	College students		R-L	EHI	10	n/a	Other	Self-report	No
Ofte (2002)	393	College students	European	R-L	n/a	5	5-point scale	Other	Self-report	No
Oldfield (1971)	1,109	College students	European	R-L	EHI	10	+ or ++ under R-L columns	Handedness	Self-report	No
Overby (1994)	963	College students	European	R-M-L	Self-classification	1	R-M-L	Other	Self-report	No
Perelle and Ehrman (1983)	2,404	General population	European	R-M-L	n/a	13	R-M-L	Handedness	Self-report	No
Perelle and Ehrman (1994)	10,781	General population	n/a	R-L	Writing hand	1	R-M-L	Handedness	Self-report	No
	21,258	General population		R-L	Writing hand	1	n/a	Handedness	No self-report	No
Peters et al. (1981)	365	College students	European	R-nonR	n/a	4	n/a	Other	Self-report	No
Peters et al. (2006)	164,230	General population	European	R-M-L	Writing hand	1	5-point scale	Handedness	Self-report	No
Plato et al. (1984)	705	General population	European	R-L	Writing hand	1	R-L	Handedness	Self-report	No
Porac (1993)	180	General population	European	R-L	n/a	6	5-point scale	Handedness	Self-report	No
	232	General population		R-L	n/a	6	5-point scale	Handedness	Self-report	No
	127	General population		R-L	n/a	6	5-point scale	Handedness	Self-report	No
	93	General population		R-L	n/a	6	5-point scale	Handedness	Self-report	No
Porac et al. (1983)	900	General population	European	R-L	Writing hand	1	R-L	Other	Self-report	No
Porfert and Rosenfield (1978)	2,107	College students	European	R-nonR	n/a	n/a	n/a	Other	Self-report	No
Preti, Sisti, Rocchi, Busca, Vellante, Camboni . . . Masala (2011)	4,232	General population	European	R-M-L	Writing hand	1	n/a	Handedness	Self-report	No
Preti et al. (2012)	1,004	General population	European	R-L	Writing hand	1	n/a	Handedness	Self-report	No
Ravichandran et al. (2017)	253	General population	European	R-nonR	Self-classification	1	R-L	Handedness	Self-report	No
Raymond, Pontier, Dufour, and Møller (1996)	350	College students	European	R-L	Writing hand	1	R-L	Handedness	Self-report	No
	542	General population	n/a	R-L	Observation of an action/ official records	1	n/a	Handedness	No self-report	Yes
	75	General population	European	R-L	Observation of an action/ official records	1	n/a	Handedness	No self-report	Yes
Reina et al. (2017)	17	General population	n/a	R-L	Self-classification	1	n/a	Handedness	Self-report	No
Reiß and Reiß (1997)	936	College students	European	R-nonR	Four items from Porac & Coren Laterality Inventory	4	R-M-L	Handedness	Self-report	No
Reiß et al. (1998)	1,223	College students	European	R-M-L	Self-classification	1	R-M-L	Handedness	Self-report	No
Rife (1940)	2,178	College students	European	R-nonR	n/a	10	R-M-L	Handedness	Self-report	No
	1,374	General population		R-nonR	n/a	n/a	R-M-L	Handedness	Self-report	No
Risch and Pringle (1985)	4,263	n/a	European	R-L	n/a	11	n/a	Handedness	n/a	No
	3,128	General population	European	R-L	n/a	1	R-M-L	Handedness	No self-report	No
Robinson et al. (2016)	708	College students	European	R-M-L	n/a	32	5-point scale	Handedness	Self-report	No
Rosenstein and Bigler (1987)	50	College students	European	R-L	EHI	10	R-L	Other	Self-report	No
Sakano and Pickenhain (1985)	998	College students	East Asian	R-M-L	n/a	5	R-M-L	Handedness	Self-report	No
	690	College students	European	R-M-L	n/a	5	R-M-L	Handedness	Self-report	No
Salmaso and Longoni (1985)	1,694	n/a	European	R-L	n/a	20	+ or ++ under R-L columns	Handedness	Self-report	No
Sanders et al. (1982)	341	General population	European	R-M-L	n/a	n/a	R-M-L	Other	Self-report	No
	224	General population	European	R-M-L	n/a	n/a	R-M-L	Other	Self-report	No
	143	General population	East Asian	R-M-L	n/a	n/a	R-M-L	Other	Self-report	No
	78	General population	East Asian	R-M-L	n/a	n/a	R-M-L	Other	Self-report	No
	55	General population	East Asian	R-M-L	n/a	n/a	R-M-L	Other	Self-report	No
	38	General population	East Asian	R-M-L	n/a	n/a	R-M-L	Other	Self-report	No
Saunders and Campbell (1985)	372	n/a	n/a	R-M-L	EHI	10	R-M-L	Handedness	Self-report	No

(*table continues*)

Table 4 (*continued*)

Study	Total (*N*)	Educational status	Ancestry	Classification of handedness	Instrument of handedness	Length of questionnaire (number of items)	Response format	Main purpose of the study	Report	Sport elite
Savel (2009)	50	General population	European	R-L	EHI	10	R-M-L	Handedness	Self-report	No
Schachter et al. (1987)	1,117	College students	European	R-nonR	EHI	10	5-point scale	Handedness	Self-report	No
Searleman and Fugagli (1987)	277	College students	European	R-L	Writing hand	1	R-L	Other	Self-report	No
Searleman et al. (1984)	3,709	College students	European	R-L	Four items from Porac & Coren Laterality Inventory	4	R-M-L	Other	Self-report	No
Searleman et al. (1979)	847	College students	European	R-M-L	n/a	14	5-point scale	Other	Self-report	No
Segal (1984)	1,577	n/a	European	R-L	Writing hand	1	R-M-L	Handedness	Self-report	No
Shan-Ming et al. (1985)	201	General population	East Asian	R-nonR	n/a	10	R-L	Handedness	Self-report	No
	231	General population	East Asian	R-nonR	n/a	10	R-L	Handedness	Self-report	No
Sherman (1979)	98	General population	European	R-nonR	n/a	14	5-point scale	Other	Self-report	No
Shettel-Neuber and O'Reilly (1983)	218	College students	European	R-M-L	n/a	1	R-M-L	Other	Self-report	No
Shimizu and Endo (1983)	4,282	General population	East Asian	R-M-L	n/a	13	5-point scale	Handedness	Self-report	No
Singh and Bryden (1994)	729	n/a	n/a	R-L	n/a	10	5-point scale	Handedness	Self-report	No
Smith (1987)	350	General population	European	R-L	EHI	10	n/a	Other	Self-report	No
Spiegler and Yeni-Komshian (1983)	1,816	College students	European	R-L	Writing hand	1	n/a	Handedness	Self-report	No
	3,632	General population	European	R-L	Writing hand	1	R-M-L	Handedness	No self-report	No
Stoyanov et al. (2011)	3,182	College students	European	R-nonR	Annett's	12	n/a	Handedness	Self-report	No
Suar et al. (2013)	3,698	General population	n/a	R-L	Writing hand	1	5-point scale	Handedness	Self-report	No
Tan (1986)	266	College students	n/a	R-M-L	Annett's	12	n/a	Other	Self-report	No
Tan (1988)	1,100	College students	n/a	R-M-L	EHI	10	5-point scale	Handedness	Self-report	No
Tapley and Bryden (1985)	1,511	College students	European	R-L	n/a	8	5-point scale	Handedness	Self-report	No
Teng et al. (1979)	2,041	College students	East Asian	R-L	n/a	12	+ or ++ under R-L columns	Handedness	Self-report	No
Thompson and Marsh (1976)	1,299	General population	European	R-M-L	n/a	4	n/a	Handedness	Self-report	No
Tonetti et al. (2012)	3,473	College students	European	R-L	EHI	10	n/a	Handedness	Self-report	No
Tran et al. (2014)	12,720	General population	European	R-M-L	n/a	12	R-M-L	Handedness	Self-report	No
Tsuang, Chen, Kuo, and Hsiao (2016)	3,445	College students	East Asian	R-L	Writing hand	1	5-point scale	Handedness	Self-report	No
Walker and Henneberg (2007)	21	General population	European	R-M-L	EHI	12	n/a	Handedness	Self-report	No
Wolf et al. (1991)	2,088	General population	European	R-L	n/a	n/a	R-M-L	Handedness	Self-report	No
Wood and Aggleton (1989)	752	n/a	European	R-M-L	Observation of an action/ official records	1	R-M-L	Other	No self-report	Yes
Wood and Aggleton (1991)	1,240	College students	European	R-L	EHI	10	R-M-L	Other	Self-report	No
Xu and Zheng (2017)	946	General population	East Asian	R-M-L	Writing hand	1	R-M-L	Handedness	Self-report	No
You et al. (2015)	40	College students	East Asian	R-M-L	Self-classification	1	n/a	Other	Self-report	No
Yule, Brotto, and Gorzalka (2014)	690	General population	n/a	R-nonR	EHI	10	n/a	Handedness	Self-report	No
Zhu et al. (2009)	18,468	General population	European	R-M-L	Self-classification	1	5-point scale	Handedness	Self-report	No

Note. EHI = Edinburgh Handedness Inventory.

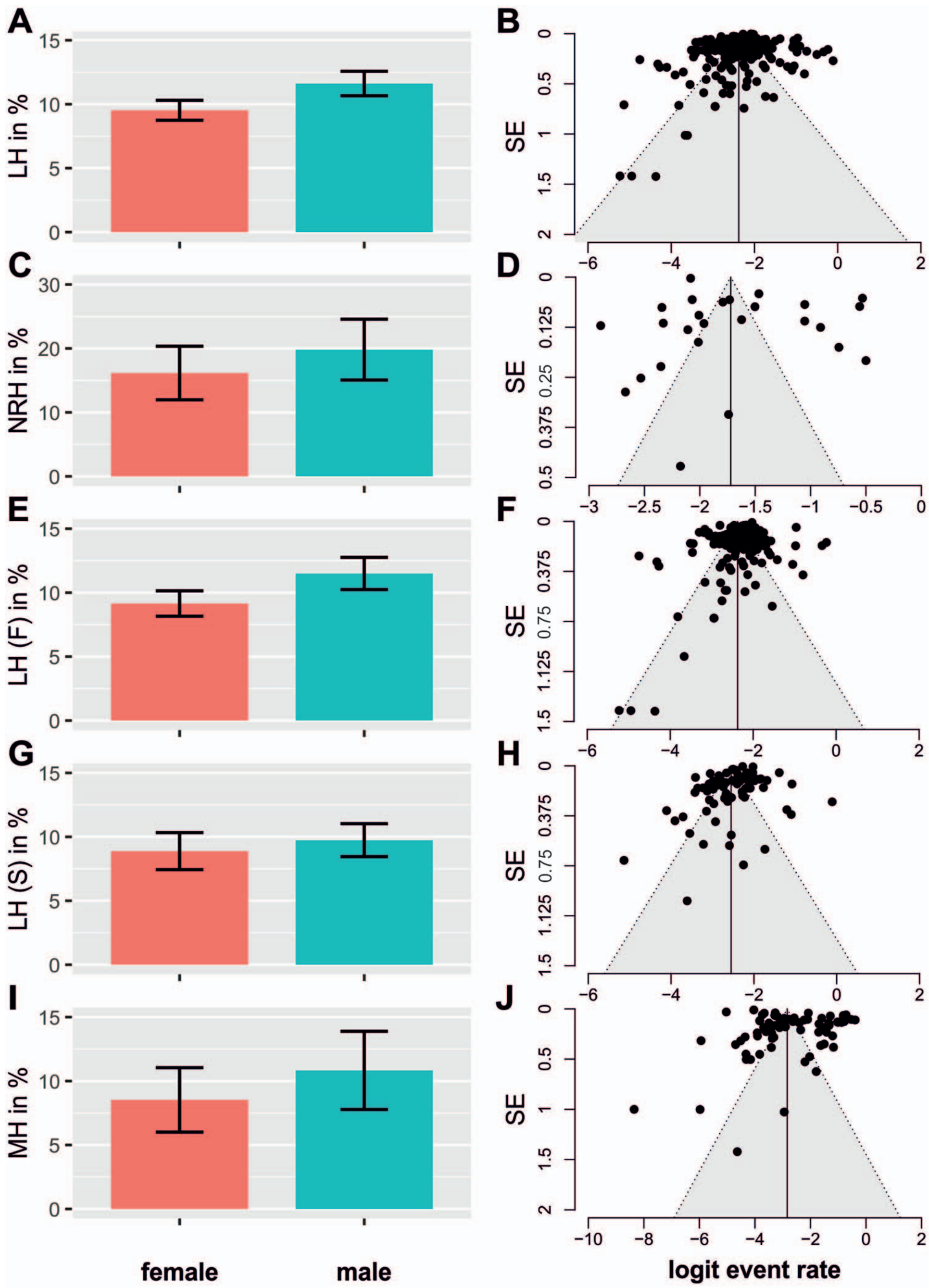

Figure 2. Sex differences in point estimates and funnel plots of standard error on log event rate for the left-handedness (total; A, B), nonright-handedness (C, D), left-handedness (forced choice; E, F), left-handedness (stringent; G, H), and mixed-handedness (I, J) comparisons. Error bars represent the 95% confidence interval. LH = left-handedness; NRH = nonright-handedness; MH = mixed-handedness. See the online article for the color version of this figure.

Moderating Variables Analysis

Because of the heterogeneity detected among studies, the moderating effects of the previously described variables were tested within the left-handedness (total) comparison, which was the most inclusive.

Publication year. Metaregression of publication year as a continuous variable revealed no evidence of a moderating effect on the prevalence of left-handedness (p = .111). There was also no indication of a Sex × Year of Publication interaction (p = .860). When year of publication was used as a categorical variable, the prevalence of left-handedness was found to be 7.19% (95% CI [5.62%, 8.76%]) when studies were published before 1976 (18 data sets), 10.73% (95% CI [8.81%, 12.65%]) when studies were published between 1976 and 1985 (69 data sets), 10.64% (95% CI [8.90%, 12.38%]) when studies were published between 1986 and 1995 (70 data sets), 11.70% (95% CI [9.57%, 13.82%]) when studies were published between 1996 and 2007 (46 data sets) and 10.77% (95% CI [8.62%, 12.92%]) when studies were published between 2008 and 2019 (57 data sets; see Figure 3). There was evidence that the prevalence of left-handedness (total) was higher in 1976–1985 (3.54%, *SE* = 1.26%, 95% CI [1.06%, 6.02%], $t(194) = 2.82$, $p < .01$), 1986–1995 (3.45%, *SE* = 1.19%, 95% CI [1.11%, 5.80%], $t(194) = 2.90$, $p < .01$), 1996–2007 (4.51%, *SE* = 1.34%, 95% CI [1.87%, 7.15%], $t(194) = 3.37$, $p < .001$) and 2008–2019 (3.58%, *SE* = 1.35%, 95% CI [0.92%, 6.24%], $t(194) = 2.65$, $p < .01$) compared with the earliest studies published before 1976. There was no indication of a Sex × Year of Publication (categorical) interaction (all $p > .315$).

Self-reporting. The prevalence of left-handedness was found to be 10.50% (95% CI [9.58%, 11.40%]) when handedness was self-reported (232 data sets) and 11.90% (95% CI [8.22%, 15.60%]) when it was not self-reported (28 data sets).

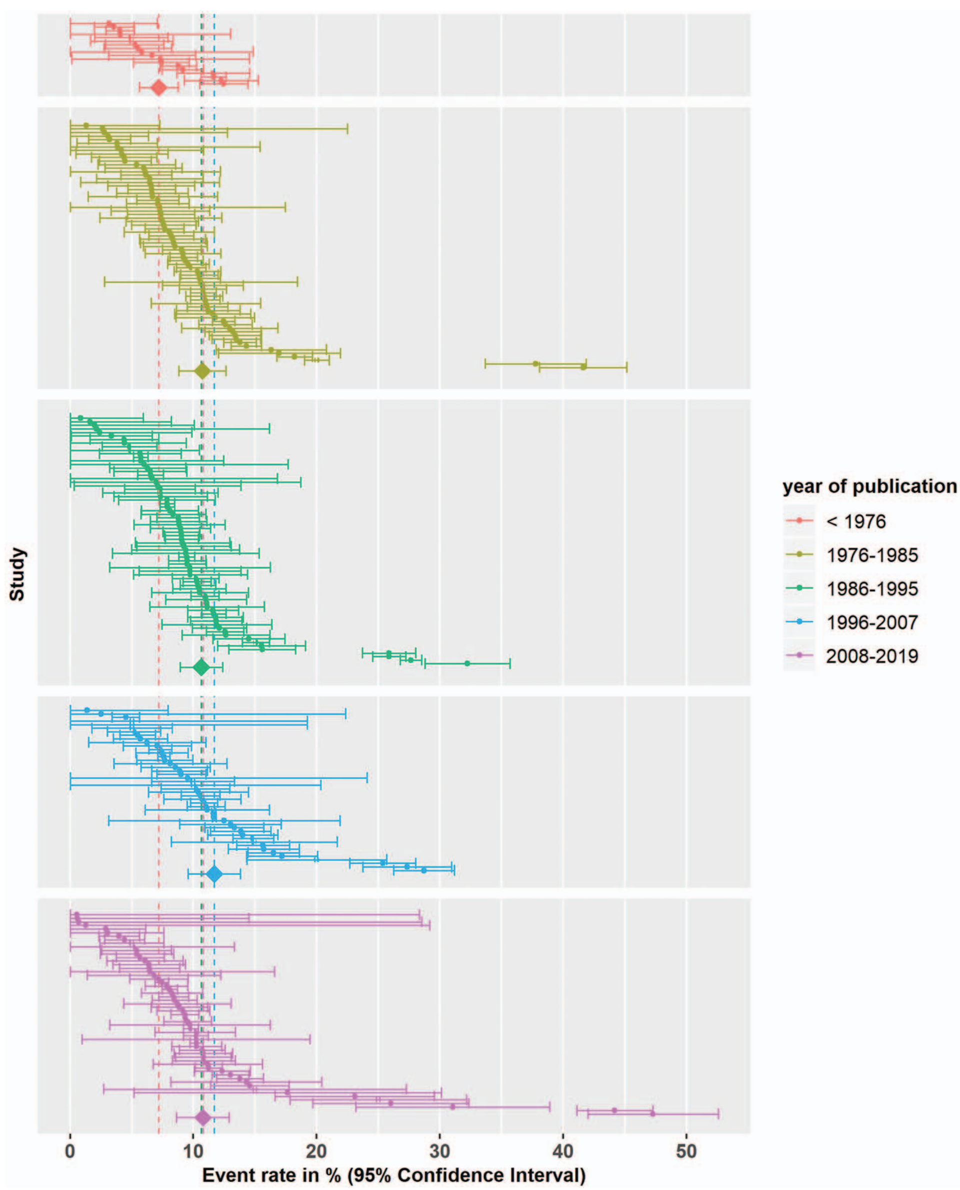

Figure 3. Forest plot for the left-handedness (total) comparison grouped by year of publication (categorical). In the plot the 95% confidence interval for each study is represented by a horizontal line and the point estimate is represented by a dot. The dashed line indicates the overall estimate of left-handedness prevalence. See the online article for the color version of this figure.

However, there was no statistical evidence for a difference (p = .458) dependent upon whether handedness was self-reported or not. There was also no indication of a Sex × Report interaction (p = .752).

Classification. There was clear evidence for a moderating effect of classification. The prevalence of left-handedness was found to be 16.57% (95% CI [12.85%, 20.30%]) when using a nonR-R classification (22 data sets), 10.16% (95% CI [9.10%, 11.20%]) when using a R-L classification (170 data sets) and 9.49% (95% CI [7.93%, 11.00%]) when using a R-M-L classification (70 data sets; see Figure 4). There was clear evidence that the estimated prevalence for the R-L classification (−6.41%, SE = 1.97%, 95% CI [−10.30%, −2.53%], $t(197) = -3.26$, $p < .01$) and the estimated prevalence for the R-M-L classification (−7.09%, SE = 2.05%, 95% CI [−11.10%, −3.05%], $t(197) = -3.46$, $p < .001$) were lower compared with the nonR-R classification. Moreover, there was evidence of a Sex × Classification interaction because of men showing more reduction of left-handedness prevalence than women when using a R-M-L classification (−3.78%, SE = 1.30%, 95% CI [−6.35%, −1.21%], $t(194) = -2.90$, $p < .01$) as compared with a nonR-R classification. There was no Sex × Classification interaction for the R-L classification (p = .084).

Instrument. The instrument used for handedness assessment was extracted from 144 studies (183 data sets). The prevalence of

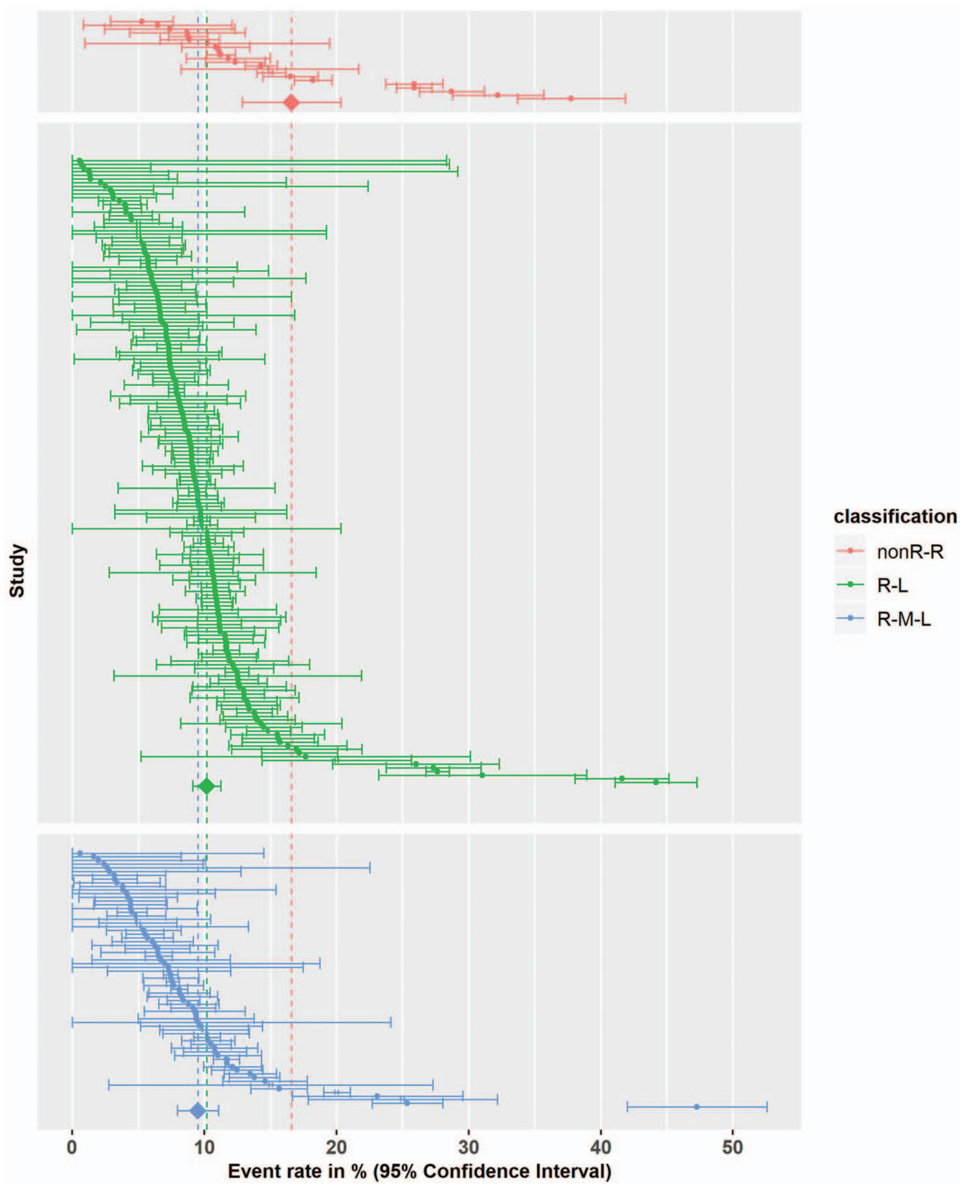

Figure 4. Forest plot for the left-handedness (total) comparison grouped by classification. In the plot the 95% confidence interval for each study is represented by a horizontal line and the point estimate is represented by a dot. The dashed line indicates the overall estimate of left-handedness prevalence. See the online article for the color version of this figure.

left-handedness was found to be 9.29% (95% CI [8.45%, 10.10%]) when assessed as writing hand (71 data sets), 13.51% (95% CI [10.29%, 16.70%]) when assessed using the EHI (47 data sets), 12.63% (95% CI [4.29%, 21.00%]) when assessed using Annett's Handedness Questionnaire (six data sets), 9.24% (95% CI [8.07%, 10.40%]) when assessed as self-classification, 9.73% (95% CI [8.23%, 11.20%]) when assessed using Briggs and Nebes Questionnaire (six data sets), 9.75% (95% CI [8.95%, 10.50%]) using Porac and Coren's Questionnaire (nine data sets) and 15.11% (95% CI [9.15%, 21.10%]) when handedness was observed (15 data sets; see Figures 5 and 6). There was no evidence that prevalence estimates were different from writing hand assessment when handedness was assessed with Annett's Handedness Questionnaire, self-classification, Briggs and Nebes Questionnaire, Porac and Coren's Questionnaire or when handedness was observed (all $p > .057$). However, there was evidence that the prevalence of left-handedness was higher when assessed using the EHI as compared with writing hand assessment (4.22%, $SE = 1.69\%$, 95% CI [0.89%, 7.55%], $t(137) = 2.50$, $p < .05$). When assessed using Annett's Hand Preference Questionnaire, the estimated prevalence of left-handedness was higher compared with writing hand only in men (3.11%, $SE = 1.02\%$, 95% CI [1.10%, 5.13%], $t(129) = 3.05$, $p < .01$). There was no evidence for an interaction of other instruments and sex (all $p > .158$).

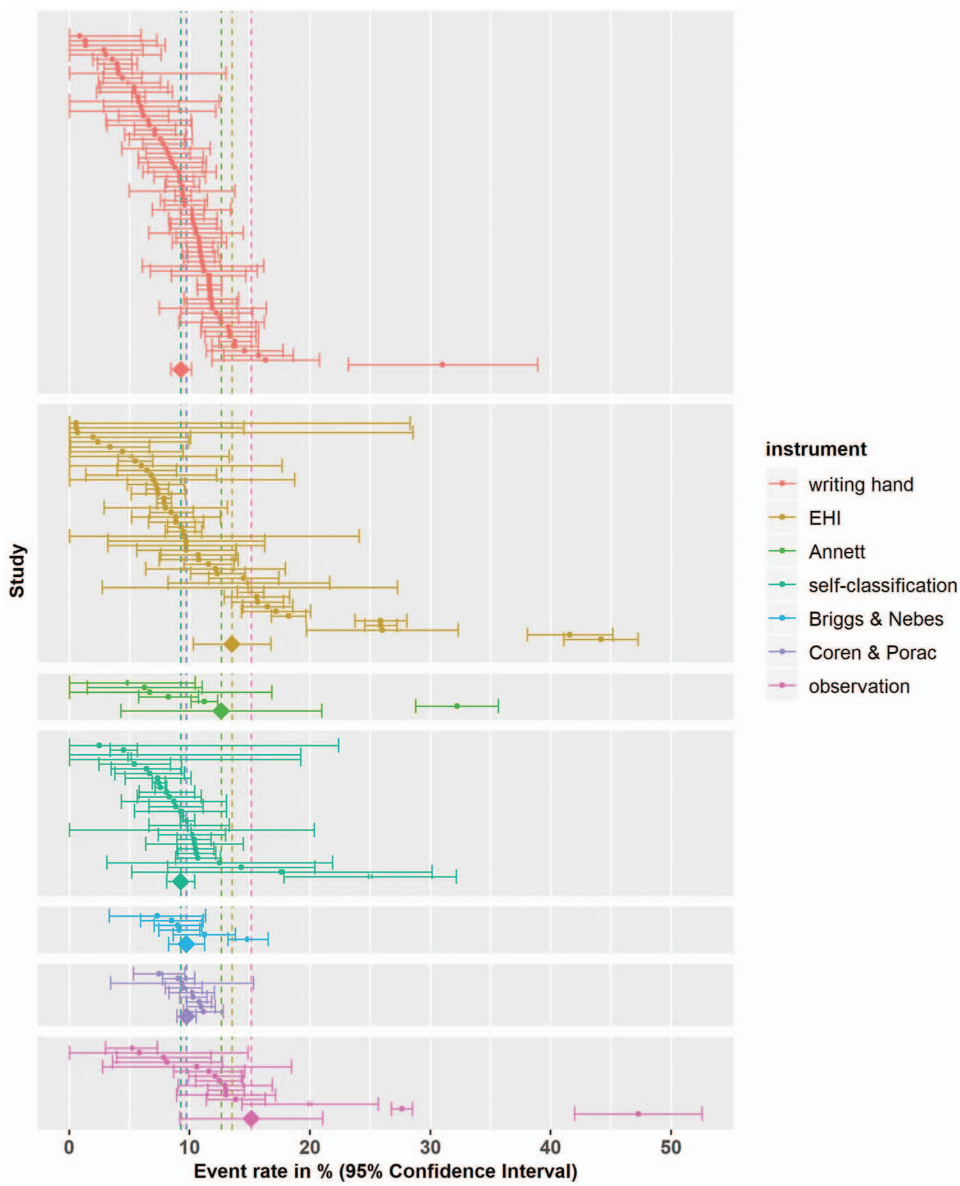

Figure 5. Forest plot for the left-handedness (total) comparison grouped by instruments used to assess handedness. In the plot the 95% confidence interval for each study is represented by a horizontal line and the point estimate is represented by a dot. The dashed line indicates the overall estimate of left-handedness prevalence. EHI = Edinburgh Handedness Inventory. See the online article for the color version of this figure.

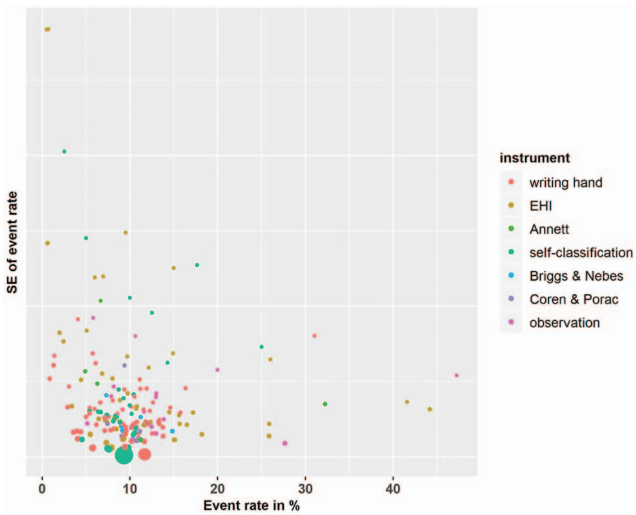

Figure 6. Scattergram visualizing the event rates of individual studies against their respective standard errors. EHI = Edinburgh Handedness Inventory. See the online article for the color version of this figure.

Writing hand was the most common criterion used to measure handedness. Therefore, the prevalence of handedness when assessed using writing hand was compared with all other instruments. The prevalence of left-handedness was found to be 11.19% (95% CI [9.97%, 12.40%]) when assessed using any instrument other than writing hand (187 data sets) and 9.32% (95% CI [8.50%, 10.10%]) when assessed as writing hand (71 data sets). There was evidence for lower prevalence of left-handedness when assessing handedness as writing hand (−1.88%, *SE* = 0.74%, 95% CI [−3.34%, −0.41%], $t(196) = -2.53$, $p < .05$). There was no evidence for a Sex × Instrument Category interaction ($p = .108$).

Purpose of study. The prevalence of left-handedness was found to be 10.10% (95% CI [8.88%, 11.30%]) when the measurement of handedness was the main purpose of the study (161 data sets) and 11.40% (95% CI [10.11%, 12.70%]) when it was not (100 data sets). There was no evidence of a moderating effect of main purpose ($p = .147$). There was also no indication of a Sex × Main Purpose interaction ($p = .053$).

Education. Level of education was extracted from 186 studies (243 data sets). The prevalence of left-handedness was found to be 11.40% (95% CI [9.86%, 12.90%]) when the study participants were college students, professionals, or university faculty (101 data sets) and 10.10% (95% CI [8.92%, 11.30%]) in general population samples (142 data sets). There was no evidence of a difference in prevalence between samples ($p = .195$), nor of an indication of a Sex × Education interaction ($p = .051$).

Ancestry. Ancestry was extracted from 167 studies (216 data sets). There was clear evidence of a moderating effect of ancestry. The prevalence of left-handedness was found to be 11.12% (95% CI [10.09%, 12.15%]) when the study participants were of European ancestry (184 data sets), 7.71% (95% CI [6.25%, 9.18%]) when the study participants were of sub-Saharan African ancestry (nine data sets), and 5.69% (95% CI [3.49%, 7.88%]) when study participants were of East Asian ancestry (23 data sets; see Figure 7). There was clear evidence of a moderating effect of ancestry with lower estimated prevalence of left-handedness for sub-Saharan African and East Asian participants (sub-Saharan Africa: −3.40%, *SE* = 0.91%, 95% CI [−5.19%, −1.61%], $t(164) = -3.76$, $p < .001$, East Asia: −5.43%, *SE* = 1.23%, 95% CI [−7.85%, −3.01%], $t(164) = -4.43$, $p < .001$) than for European participants. There was no evidence of a Sex × Geographical Ancestry interaction (all $p > .594$).

Questionnaire length. Metaregression of questionnaire length revealed no evidence of a moderating effect on the prevalence of left-handedness ($p = .133$). There was also no indication of a Sex × Questionnaire Length interaction ($p = .153$).

Response format. Response format was extracted from 133 studies (172 data sets). The prevalence of left-handedness was found to be 9.74% (95% CI [7.90%, 11.60%]) when participants had to respond making a forced choice between right and left (43 data sets), 10.34% (95% CI [9.00, 11.70%]) when participants were given a three-way response format (79 data sets), 11.26% (95% CI [8.07%, 14.40%]) when participants could respond on a 5-point scale (40 data sets), and 10.50% (95% CI [5.98%, 15.00%]) when the original response format of the EHI was given (10 data sets). Compared with a binary format, the prevalence estimate did not differ when participants were given a three-way response format, a 5-point scale or when the original response format of the EHI was given (all $p > .410$). There was no evidence of a Sex × Response Format interaction (all $p > .299$).

Sporting elite. Left-handedness was higher in the elite sport group (14.70%, 95% CI [9.72%, 19.80%]) compared with the general population (10.40%, 95% CI [9.52%, 11.30%]). However, the former group was based on a much smaller sample (12 data sets) and presented higher variance probably because of a wide range of different sports. The comparison between general population and sporting elite samples failed to reach significance ($p = .095$). There was also no indication of a Sex × Sport interaction ($p = .211$).

Mean age. Mean age was extracted from 63 data sets (54 studies). Metaregression of mean age revealed no evidence of a moderating effect of mean age on the prevalence of left-handedness ($p = .102$). There was also no indication of a Sex × Age interaction ($p = .124$).

Discussion

The present set of five meta-analyses integrates data on n_t = 2,396,170 individuals. Depending on the criterion for the classification of study participants, the prevalence of left-handedness was in the range of 9.34% (using the most stringent criterion of left-handedness) to 18.10% (using the most lenient criterion of nonright handedness), with an overall estimate of 10.60% for left-handedness (total). The estimate dropped to 10.40% when excluding the studies that assessed the handedness of elite athletes, who can be argued to be under selection bias according to theories suggesting a left-handedness advantage in some sports (e.g., Loffing, 2017). A sex difference was detected regardless of how participants were grouped, in line with previous findings (Martin, Papadatou-Pastou, Jones, & Munafò, 2010; Papadatou-Pastou et al., 2008).

The field of handedness is known for the notorious variations in the methodology that is used to actually measure handedness in

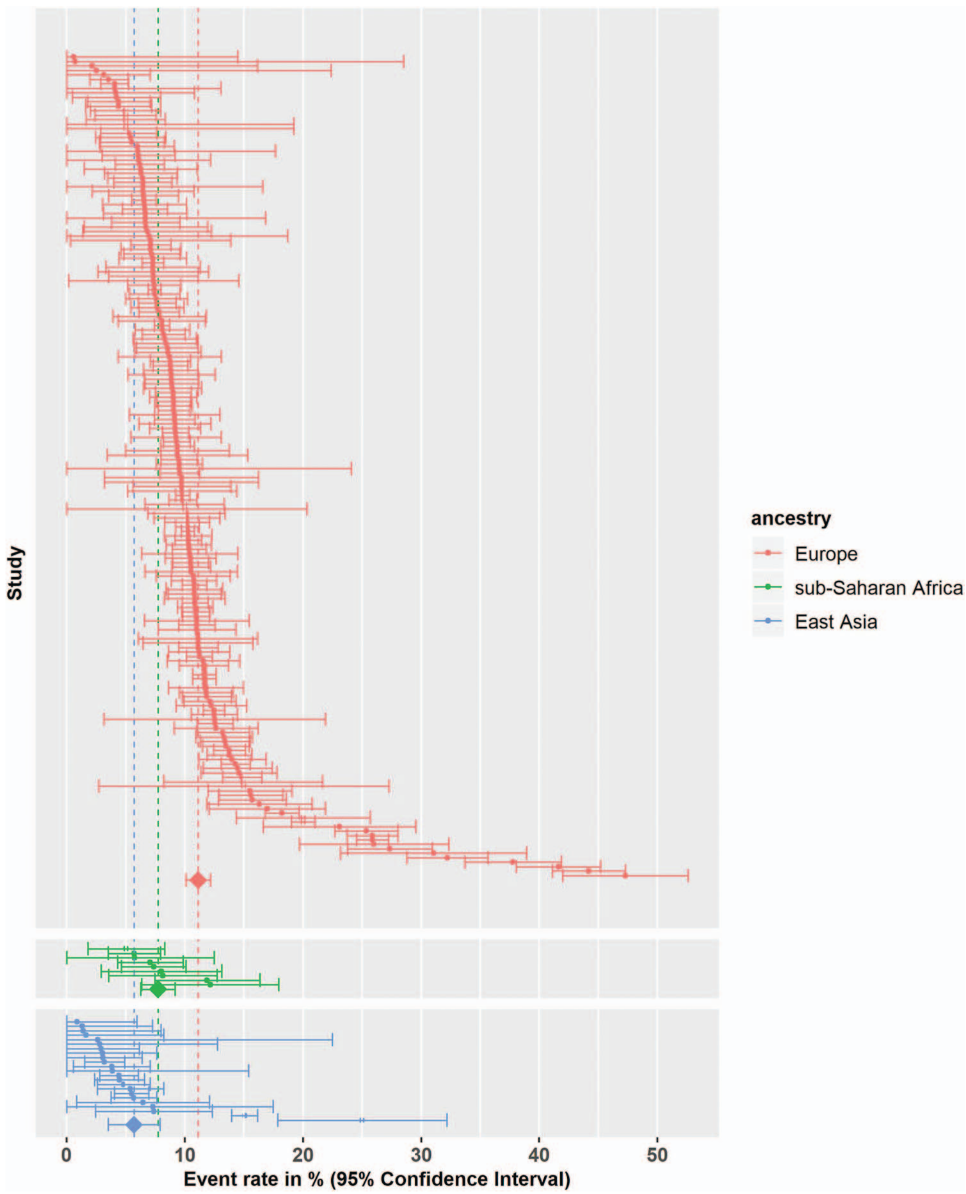

Figure 7. Forest plot for the left-handedness (total) comparison grouped by geographical ancestry. In the plot the 95% confidence interval for each study is represented by a horizontal line and the point estimate is represented by a dot. The dashed line indicates the overall estimate of left-handedness prevalence. See the online article for the color version of this figure.

different studies. This was reflected in the number of moderators that were found to effect the estimate of prevalence rates for left-handedness (total). The instrument used to measure handedness produced different prevalences with self-report of handedness resulting in the lowest prevalence of left-handedness (9.24%), closely followed by writing hand (9.29%), with studies using different questionnaires giving a prevalence of around 10–13% and observation giving the highest prevalence (15.11%). Indeed, we have previously shown in a sample of 200 participants balanced for handedness and sex that participants' responses match when asked to indicate their handedness as writing hand and when asked to self-report their handedness and that there is an average 6.9% mismatch between writing hand and hand preference questionnaires (Papadatou-Pastou et al., 2013). When handedness information was collected by self-report measures (e.g., questionnaires filled in by the participants), the prevalence was slightly lower (10.50%) compared with when it was not (e.g., the prevalence when measured by filial report was 11.90%), but there was no clear statistical evidence for this difference. There was also no clear statistical evidence for the moderating effect of the number of items used to assess handedness or similarly for the response type available to participants. Therefore, shorter questionnaires can be used in place of longer and more time-consuming ones without affecting the findings.

Another aspect troubling handedness researchers is that different studies classify their participants using different groupings, all the way from two-way groupings (e.g., R-L or R-nonR) to seven or more groupings. To account for this variance we performed different meta-analyses for the different groupings. We also investigated the possible moderating effect of classification within the left-handedness (total) grouping, which included all studies. We found that the prevalence of left-handedness drops as criteria become stricter. More specifically, the prevalence of left-handedness was 16.57%, 10.16%, and 9.49% when using a nonR-R, R-L, and R-M-L classification, respectively, with a clear moderating effect of classification ($p < .001$). This finding highlights the importance of reaching a consensus among handedness researchers on what the optimal classification of handedness is. We suggest that researchers report at least two different classifications of handedness (R-L and R-M-L) and that they further make their raw data available in open access repositories, such as the Open Science Framework (osf.org).

The issue of handedness classification is particularly relevant to the middle category in handedness studies, usually referred to as ambidexterity or mixed-handedness. For example, large studies such as the GWAS by Cuellar Partida et al. (2019, preprint) used a classification of ambidexterity based on self-reported hand preference for writing. The ambidexterity category was available for the U.K. Biobank sample (1.6%) and 23andMe (2.5%). Other studies, however, used more inclusive criteria for the middle category, resulting in a higher percentage of individuals in this group. For example, our data show that LQ measures identify 9.33% mixed-handedness, which is a figure almost as high as left-handedness. As the exact definition of the ambidextrous/mixed-handed classification might influence the outcome of studies, it is key to ensure that future studies capture this dimension beyond the binary left or right preference. The ability to systematically capture mixed-handedness in large studies might improve the power to address some of the questions around handedness research. For example, identifying the ~9% of mixed-handed individuals in the U.K. Biobank might improve the resolution of genetic mapping.

Year of publication was also found to affect the prevalence of handedness, although only when measured as a categorical variable. Thus, in more recent publications, the reported prevalence of left-handedness was higher than in very early studies (published before 1976). This is consistent with the results of cross-sectional studies which typically report lower rates of left-handedness among older compared with younger generations (Lee-Feldstein & Harburg, 1982) and new large-scale studies that show increased left-handedness among younger individuals (de Kovel et al., 2019). Fleminger, Dalton, and Standage (1977) have considered the age differences in handedness to be a natural tendency toward dextrality. Lalumière et al. (2000) argue that this trend reflects either cohort effects or biased mortality rates associated with handedness, a rather popular view (Coren, 1989; Coren & Halpern, 1991). Porac and Coren's (1981) developmental hypothesis, on the other hand, postulates that this decrease in the prevalence of left-handedness reflects the pressure of living in a right-handed world. Another influential theory is that of the gradual easing of cultural pressures against sinistrality (Schachter, Ransil, & Geschwind, 1987). However, increasing rates of left-handedness have been found to be coupled with increasing rates of left-arm waving, a behavior not subject to social pressure, as studied in old films (McManus & Hartigan, 2007). A variant of this theory is that because in the earlier years of the last century left-handedness represented a social stigma, individuals may have concealed their true handedness in questionnaire surveys (McManus, 1984). Gilbert and Wysocki (1992) report data from over 1,100,000 individuals and show that the prevalence of left-handedness was only 3% for those born in 1900 rising up to almost 12% for those born in 1945 onward. The effect has also been attributed to the underreporting of left-handedness in parents by their offspring (Kang & Harris, 1996). On the other hand, McManus, Moore, Freegard, and Rawles (2010) claim that left-handers are more likely to respond to surveys about handedness and that this response bias is growing. The age effect might also be an artifact because of the fact that relearning is more likely for older people. The increase in the estimated left-handedness rate further indicates that active instructions are likely to be a nongenetic factor that influences handedness, as this increase in left-handedness over time is likely to be caused by a reduction of forcing left-handers to use the right hand for writing in schools (de Kovel et al., 2019; Klöppel, Mangin, Vongerichten, Frackowiak, & Siebner, 2010).

Participants' characteristics were also found to moderate the estimate of the prevalence of left-handedness. Ancestry group was found to moderate the estimates of the prevalence of handedness in different studies, supporting the idea that cultural effects affect handedness (Laland, 2008; Laland, Kumm, Van Horn, & Feldman, 1995). Participants of European ancestry had a much higher prevalence of left-handedness (11.12%) compared with participants of sub-Saharan African ancestry (7.71%), or of East Asian ancestry (5.69%). The moderating effects of ancestry could be either because of (a) genetics, (b) prenatal testosterone levels and its geographical variations (Raymond & Pontier, 2004), or (c) cultural factors. We favor the last explanation, as studies have shown that participants coming from families with backgrounds with low percentages of left-handedness, but having been raised in the western world show similar prevalence of left-handedness as the population of the country they have been raised in (Laland et al., 1995). This might happen because of direct instructions by parents and teachers or also through nonexplicit model learning.

The cultural hypothesis is also supported by a recent study showing that the rate of nonright-handedness in Hong Kong (about 8%) is higher than in most previous studies in Asian populations (Zheng et al., 2019, preprint). This could be because of the greater Westernization in Hong Kong compared with many other Asian areas. The prevalence of nonright-handedness increased up to 13% when it was assessed using the preferred hand for drawing, not writing. This suggests that cultural pressures might be specific for writing and do not affect other behaviors to the same extent.

Studies that included individuals with higher levels of education (e.g., college students, professionals, or university faculty) reported elevated levels of left-handedness prevalence (11.40%) compared with studies that used general population samples (10.10%), albeit there was no statistical evidence for this difference. Similarly, members of sporting elites were found to have a 14.70% prevalence of left-handedness as opposed to 10.40% for the general population. The trend toward higher left-handedness prevalence in sporting elites is possibly because of the nature of interactive sports giving left-handers an advantage as right-handers have less practice with left-handed opponents (Loffing, 2017;

Loffing & Hagemann, 2012, 2016; Wood & Aggleton, 1989). Even though the present systematic review did not locate enough data sets to test this hypothesis, the two studies that did make this comparison showed that it is interactive sports that are associated with elevated levels of left-handedness (Grouios et al., 2000; Loffing, 2017). However, Loffing, Sölter, and Hagemann (2014) showed that left-preference for sport does not always translate into left-handedness for the everyday tasks typically assessed in laterality studies.

Findings also show an effect of sex, suggesting a lower prevalence of left-handedness (total) in women (9.53%) than in men (11.62%). This supports the hypothesis that sex hormones might be one of the nongenetic factors that influence the ontogenesis of handedness and hemispheric asymmetries in general (Geschwind & Galaburda, 1987; Hausmann, 2017). Note that a similar sex effect (women = 8.6%, men = 10.6%) was also observed in a recent analysis of nongenetic influences on handedness in the U.K. Biobank Cohort (de Kovel et al., 2019). Such an independent replication of an effect in both a large-scale individual study and a large-scale meta-analysis indicates that this effect is unlikely to be caused by spurious findings. The most obvious genetic effect on sex-bias would implicate the sex chromosomes. It has been argued that left-handedness could be associated recessively, and with low penetrance, with a genetic variation located on the X chromosome (Jones & Martin, 2000; but also see McManus, 2010). Priddle and Crow (2013) have suggested that the X chromosome and specifically the protocadherin 11X/Y (*PCDH11X/Y*) gene pair has a central role for handedness, but adequate empirical support has not yet been amassed. Moreover, Arning et al. (2015) reported a role for the androgen receptor CAG-repeat length, located on the X chromosome for handedness, which partly replicated the work of Medland et al. (2005). Of note, a model for the genetics of sex differences in handedness has been suggested by McManus and Bryden (1992), implying that an X-chromosomal modifier gene might be responsible for sex differences in handedness. However, the most recent GWAS did not detect any associations on the X chromosome (Cuellar Partida et al., 2019).

In the current study, only studies measuring hand preference and not hand skill were included. Preference and skill represent two rather distinct concepts which have been suggested to be independently lateralized (Triggs, Calvanio, Levine, Heaton, & Heilman, 2000), with preference being considered as primary (McManus, Murray, Doyle, & Baron-Cohen, 1992). Nevertheless, preference is correlated with measures of relative hand skill with an estimated correlation of magnitude of .62 to .73 (Todor & Doane, 1977) or more recent estimates of .50 to .57 (Triggs et al., 2000), while Corey, Hurley, and Foundas (2001) found that in more than 90% of cases preference-based groups corresponded to groups based on relative hand skill. A recent study also showed that the correlation between hand preference and relative hand skill highly depends on which test is used to assess relative hand skill (Buenaventura Castillo, Lynch, & Paracchini, 2019, preprint). The authors assessed the relationship of hand preference with measures of relative hand skill (pegboard task, marking squares, and sorting matches) and relative hand strength (grip strength). The tests showed low correlations with each other (r = .08 to 0.3) and also differential correlations with hand preferences, indicating that different measures of relative hand skill cannot be used interchangeably. Andersen and Siebner (2018) suggest that right-left asymmetries in dexterity need to be taken into account when testing for structural correlates of preferred hand use. This relationship allows for the results of the present systematic review and meta-analysis on hand preference to provide some insight with regards to the prevalence of hand skill.

Moreover, only direction (e.g., right- vs. left-handedness) and not degree of hand preference (e.g., weak vs. strong handedness) was taken into account in the present meta-analyses. This distinction is an important one, as variations in the degree of hand preference, measured using a five-item hand preference inventory, have been shown to be associated with differences in structural lateralization in somatomotor regions of the brain as well as in areas underlying high level cognitive control of action (McDowell, Felton, Vazquez, & Chiarello, 2016). Moreover, some specific genetic polymorphisms such as in the *PCSK6* gene have been associated with degree but not direction of hand preference as assessed by the EHI (Arning et al., 2013). Of note, genetic variation in *PCSK6* has also been related to differences in relative hand skill (Brandler et al., 2013).

Cognitive differences have further been suggested between individuals with weak and strong hand preference (e.g., Prichard, Propper, & Christman, 2013) or inconsistent and consistent handedness (Christman & Prichard, 2016). Yet, most journal articles do not report a continuous score of handedness for their participants; thus, not providing the data for such an analysis of degree of handedness to take place within the present study.

Alongside our main findings concerning the prevalence of handedness, this systematic review revealed that studies are not consistent with regard to the instruments they use to measure handedness or the classification scheme they use. Moreover, there is often poor reporting of the study details as well as of the population characteristics (e.g., age). This posed a problem in the present meta-analyses, as a large number of data sets had missing information, which hindered the power of our moderating variables analysis. We suggest that study characteristics, such as instrument used to measure handedness (including questionnaire length and individual item content), response format, classification scheme, country in which the study took place, as well as population characteristics, such as sex, age, ancestry, and educational level of the participants, are reported in all handedness studies. Moreover, we urge researchers to report handedness for writing hand for their participants along with their EHI laterality index. These two instruments are the most popular, short, and simple and should provide a solid base for comparison among studies.

Overall, the present meta-analysis showed that left-handedness frequency approximates almost exactly to 10%. Our data identify some geographical variation but we cannot confidently conclude whether this is the result of culture rather than genetics. Nevertheless, we presented some evidence suggesting that with reduction of cultural pressure, left-handedness appears to converge on a figure of 10%. A more accurate picture can only be obtained with more data from underrepresented ancestries.

Cultural pressures should apply specifically to hand preference for writing, which is the most universally used handedness measure. As we illustrated, this is a convenient yet crude measure that has the potential to lead to some artifacts and fluctuations especially when external social pressures are in force, for example in older generations and in specific cultural groups. These observations reinforce our recommendation of defining universal criteria for a measure of handedness. Such criteria are essential for our ability to compare effectively different studies as well as for guiding the design of future studies.

The results of our meta-analysis clearly indicate that both assessment instrument and classification scheme for handedness significantly affect handedness rates. Therefore, our findings reveal that it is vital for the progress of clinical genetic studies on handedness to adopt a universal classification of handedness definition and its assessment so that all future large scale studies will be comparable with each other. It is recommended that researchers would not only assess self-reported handedness and writing hand, but also include a handedness preference measure such as the EHI with categories for ambidexterity.

The present set of meta-analyses summarizes the vast field of handedness research in terms of the prevalence of hand preference in adult healthy populations. It shows in a robust way that the prevalence of left-handedness is around 10% regardless of the special features of each study, with the best overall estimate stemming from these published studies being 10.60% (10.40% excluding elite athletes). We claim that the same evolutionary mechanisms should apply worldwide to maintain the roughly 1:10 ratio of left- versus right-handers found in this meta-analysis. At the same time, the exact prevalence of left-hand preference appears to be moderated by cultural factors. The moderators identified here, make for excellent candidates for future epigenetic studies. Handedness research is hindered by publication bias, *p*-hacking, small samples, and heterogeneity criteria. Our study clearly shows how handedness frequency is affected by assessment and definition of handedness. Our data provide a comprehensive reference for evaluating such handedness differences supporting the design and interpretation of handedness studies. We further argue that it is crucial for the field of handedness and laterality for a consensus to be reached on how handedness should be measured and classified.

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