Right-handers have negligibly higher IQ scores than left-handers: Systematic review and meta-analyses

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Abstract

The relationship between intelligence and handedness remains a matter of debate. The present study is a systematic review of 36 studies (totaling 66,108 individuals), which have measured full IQ scores in different handedness groups. Eighteen of those studies were further included in three sets of meta-analyses (totaling 20,442 individuals), which investigated differences in standardized mean IQ scores in (i) left-handers, (ii) non-right-handers, and (iii) mixed-handers compared to right-handers. The bulk of the studies included in the systematic review reported no differences in IQ scores between left- and right-handers. In the meta-analyses, statistically significant differences in mean IQ scores were detected between right-handers and left-handers, but were marginal in magnitude (d = -0.07); the data sets were found to be homogeneous. Significance was lost when the largest study was excluded. No differences in mean IQ scores were found between right-handers and non-right-handers as well as between right-handers and mixed-handers. No sex differences were found. Overall, the intelligence differences between handedness groups in the general population are negligible.

Keywords: Intelligence; IQ; Hand preference; Cognitive ability; Cerebral laterality; Handedness

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1. Introduction

Left-handedness has been associated with creativity (e.g., Badzakova-Trajkov et al., 2011), homosexuality (Lalumiere et al., 2000), deafness (Papadatou-Pastou and Sáfár, 2016), learning difficulties, such as dyslexia (e.g., Vlachos et al., 2013), disorders, such as schizophrenia (Sommer et al., 2001) and autism (Markou et al., 2017), autoimmune disorders (e.g., Geschwind and Behan, 1982), even with decreased survival fitness (e.g., Coren and Halpern, 1991), to name but a few of the associations. Left-handedness has been further associated both with a cognitive deficit (e.g., Nicholls et al., 2010; Nicholls et al., 2012; Resch et al., 1997) and a cognitive advantage (e.g., McManus and Mascie-Taylor, 1983).

A possible association between handedness and cognitive ability (or lack thereof), apart from its intrinsic interest, is important because intelligence has been itself associated with a number of outcomes, such as school achievement (e.g., Deary et al., 2007; Johnson et al., 2006), socioeconomic success (e.g., Strenze, 2007), job performance (e.g., Gottfredson, 1997; Kuncel and Hezlett, 2010), and health and longevity (e.g., Gottfredson and Deary, 2004; Wraw et al., 2015), even though findings are not always straight forward (e.g., Zagorsky, 2007; Nedelec et al., 2012; Mears and Cochran, 2013). Showing that individuals in different handedness groups do not present differences in their IQ scores, is also important for educational purposes: it has been found that teacher judgments of student intelligence predict life outcomes even 40 years later (Fischbach et al., 2013). Hence, teachers who might erroneously believe that their left-handed pupils (or their right-handed ones, for that matter) are more intelligent might implicitly offer them an undue advantage compared to the other students. In a recent survey of 573 prospective Greek teachers, 38.6% responded positively to the question “Left-handed individuals don't have a higher IQ than right-handed individuals”, 34.5% responded negatively (thus agreeing that this statement is true), and 26.9% responded that they did not know (Papadatou-Pastou et al., 2017). In other words, at least one third of the prospective teachers believed left-handers are more intelligent than right-handers.

A recent meta-analysis (Papadatou-Pastou and Tomprou, 2015) showed that individuals with intellectual disability present elevated levels of both left-handedness and non-right-handedness (which is a more lax definition of atypical handedness, comprising both left-handedness and mixed-handedness) compared to the general population. The same meta-analysis showed further that intellectually gifted individuals do not differ from the general population in terms of non-right-handedness, but do differ in terms of left-handedness, as they seem to be 0.76 times less probable to be left-handed compared to the general population. The Papadatou-Pastou and Tomprou (2015) meta-analysis thus compared individuals with intellectual disability with typically developing ones, as well as gifted individuals with typically developing ones in terms of their handedness. In other words, the groupings of the participants were made according to intelligence and those groups were then compared in terms of handedness. A similar, yet different question has not been investigated to date, namely the question of whether differences in intelligence exist between handedness groups. In this case, participants would be grouped according to handedness and then compared in terms of intelligence.

1.1. Handedness and intelligence

When it comes to the relationship between handedness and intelligence, findings are contradictory. Some studies support the hypothesis that atypical handedness is linked to cognitive deficits (e.g., Briggs et al., 1976; Nicholls et al., 2010, 2012), other studies have shown elevated levels of cognitive abilities in left-handers (e.g., Ghayas and Adil, 2007; Levander et al., 1989), while others have failed to report a relationship between handedness and intelligence (e.g., McManus et al., 1988; Witelson et al., 2006).

Levy (1969) was the first to report data linking left-handedness to cognitive deficits, even though his study was based on a small sample of 10 left-handers and 15 right-handers. In 1976, Briggs et al. studied 68 left-, 68 mixed-, and 68 right-handed undergraduate students and found that left- and mixed-handers had a significantly lower full-scale IQ as measured by the Wechsler Adult Intelligence Scale (WAIS) than right-handers. The same year a large sample study comprising 11,316 11-year-old schoolchildren corroborated these findings (Calnan and Richardson, 1976). In 1983, McManus and Mascie-Taylor found that left-handers scored statistically significantly lower on g than right-handers, by analyzing official data from 12,779 children derived from the National Child Development Study. Resch et al. (1997) studied 545 young adults, using the Culture Fair Intelligence test and concluded that left-handers had lower scores mostly on non-verbal IQ, when superior abilities were detected for strong right-handers. In 2010, Nicholls et al. used data on 825 individuals from the Brain Resource International Database and in 2012 data on 17,198 individuals from the British Cohort Study and both times reached the conclusion that rightward asymmetry was associated with higher general cognitive ability. Of note, Nicholls et al. (2010) comment that the effects are subtle and might only be identified in large-scale studies.

However, elevated levels of cognitive ability in left-handers have also been reported (Annett and Manning, 1989; Ghayas and Adil, 2007; Heim and Watts, 1976;

Levander et al., 1989; Ounsted et al., 1985); even intellectual giftedness in individuals with atypical handedness (e.g., Benbow, 1986; Ostatnikova et al., 2002; but also see Papadatou-Pastou and Tomprou, 2015). For example, in the Ounsted et al. (1985) study, where 217 right- and 25 left-handers were tested, left-handers scored higher compared to right-handers on 12 out of the 15 ability tests comprising the British Ability Scale (BAT). In 2007, Ghayas and Adil administered Raven's Progressive Matrices (Raven, 1976) in 150 intermediate, graduate, and post-graduate students (75 right- and 75 left-handers). The results indicated superiority in favor of the left-handers.

The cases in which studies have failed to find any difference between left- and right-handers are also numerous (e.g., Bishop, 1980; Hardyck et al., 1976; Keller et al., 1973; Koufaki, 2014; Newcombe and Ratcliff, 1973; Tomprou, 2013). For example, Newcombe and Ratcliff (1973) used the WAIS in a sample of 823 individuals (26 left-, 139 mixed-, and 658 right-handers) and no effect of handedness was detected. Hardyck et al. (1976) similarly found no effect of handedness on intelligence in 7688 6-12 years old children (741 left- and 6947 right-handers), who had been evaluated for intelligence using the Lorge-Thorndike Intelligence Test. Consistent with this pattern, Inglis and Lawson' study (1984) also found no IQ differences between 1710 right- and 170 left-handers. In 2006, Witelson et al. assessed the intelligence of 100 non-neurological cancer patients using the WAIS test and no effect of handedness was reported either.

Of note, the studies discussed above have focused on the direction of handedness, comparing right- to left-handers. When it comes to the relationship between degree of handedness and achievement in intelligence tests, evidence is scarce. Only three studies have reported pertinent findings to date to the best of our knowledge. Caplan and Kinsbourne (1981) reported that neither side nor strength of preference was related to any variable they investigated, among which were three subtests of the WISC-R (vocabulary, information, block design; Wechsler, 1974), but they reported no numerical data. McManus et al. (1988) also found no correlation of degree of hand preference, as assessed using a 10-item performance battery, with general intelligence, as assessed by Raven's Progressive Matrices. However, in a seminal study, Crow et al. (1998) analyzed data provided by the National Child Development Study for which 12,770 children at the age of 11 were examined. Cognitive deficits for individuals close to the point of equal hand skill were robustly shown. Furthermore, Papadatou-Pastou and Tomprou's meta-analysis (2015) showed that elevated levels of mixed-handedness are to be found in intellectually disabled individuals compared to the general population.

A large number of studies do not report on differences between right- and left-handers in overall IQ scores, but focus on distinct cognitive abilities, for example reading or spatial ability (e.g., Keller et al., 1973, Peters et al., 2006, respectively). Some of these studies suggest that left-handers achieve lower scores on performance IQ (Bradshaw et al., 1981; Hicks and Beveridge, 1978; Resch et al., 1997), while some others argue that left-handers tend to perform better on verbal intelligence (Johnson and Harley, 1980; Mascie-Taylor, 1980; Sherman, 1979). Others also suggest that left-handers perform better on numerical tasks (Heim and Watts, 1976) or visuo-spatial ability (Levander et al., 1989). A meta-analysis on the relationship of handedness with verbal and spatial ability (Somers et al., 2015) showed a small but significant effect favoring right-handedness for overall spatial ability, but no difference between left- and right-handers for verbal ability.

1.2. Possible factors for the discrepancy in research findings

The discrepancy in the literature can be understood if one takes into consideration differences in study design. Handedness assessment varies between studies, based on whether hand preference or more rarely relative hand skill (e.g., Sherman, 1979; McManus et al., 1988, respectively) and whether degree or direction of handedness (e.g., Resch et al., 1997; Caplan and Kinsbourne, 1981, respectively) is measured. Handedness assessment can also vary when different instruments are used to measure handedness. For example, some studies use handedness questionnaires (e.g., Keller et al., 1973), others self-report (e.g., Inglis and Lawson, 1984), when others use hand performance measures (e.g., Nicholls et al., 2012). In the case of performance measures, some studies use a large number of manual tasks (e.g., Witelson et al., 2006, 12 items) when others use just one to three items (e.g., Calnan and Richardson, 1976).

In addition, while in some cases handedness is treated as a continuous variable (e.g., Crow et al., 1998; Nettle, 2003; Resch et al., 1997), in other studies handedness is treated as a categorical variable, with distinct categories based either on a binary (left- and right-handers) or a three-way (or more) handedness classification (left-, mixed- and right-handers) (e.g., Annett and Manning, 1989; Corballis et al., 2008, respectively). Moreover, different cut-off criteria have been used to separate handedness groups. For instance, Newcombe and Ratcliff (1973) used a 7-item handedness questionnaire to assess hand preference. The participants who showed a uniform pattern for all the seven activities were classified as right- or left-handers. The remaining participants were classified as mixed. In contrast, in Sherman's (1979) study, a 14-item hand preference questionnaire was used, to which the subjects were asked to answer on a 5-point scale, with scores ranging from 14 to 70. Participants who scored from 14 to 17 were registered as right-handers, and participants scoring at least 40 were considered to be left-handed.

Differences may also be attributed to the different methods that have been used to measure intellectual ability. A number of different instruments have been used, for example, the Wechsler Scale (e.g., Bradshaw et al., 1981; Fagan and Dubin, 1974), Raven's Progressive Matrices (e.g., Ghayas and Adil, 2007), the California test of Mental Maturity (e.g., Keller et al., 1973), the Culture Fair Intelligence Test (e.g., Hicks and Beveridge, 1978), the Lorge-Thorndike Intelligence Test (e.g., Hardyck et al., 1976), when in some cases a battery of IQ tests was used (e.g., Annett and Turner, 1974; Levander et al., 1989).

Moreover, specific characteristics of the sample, such as the age of the participants, or the sex ratio in the sample, could also affect the results of a study. A large meta-analysis has shown that males are 23% more likely to be left-handed compared to females (Papadatou-Pastou et al., 2008; Martin et al., 2010). As an illustration, if for females the rate of left-handedness is 10%, then the male rate would be 12%. Sample's age is equally important; a positive correlation has been found between intelligence and the trajectory of change in the thickness of the cerebral cortex (rather than cortical thickness itself) during a child's developmental process in a large longitudinal study of 307 typically developing individuals (Shaw et al., 2006). The differences in the shapes of trajectories in cortical thickness between individuals with superior intelligence, high intelligence, and average intelligence in prefrontal and temporal areas were highly significant (all $p < 0.001$). Especially for males, handedness is thought to be established later than girls (Annett, 1974; Archer et al., 1988), therefore age and sex might have a combined effect.

Last but not least, differences can also be a result of secular change, as left-handedness was considered to be socially unacceptable in earlier decades (Douglas et al., 1967; Hardyck et al., 1976; Wilson and Dolan, 1931). Therefore, it could be the case that a portion of the left-handers in earlier studies has not been classified correctly.

1.3. Potential sources of differences in intelligence between right- and left-handers

Many theories have been proposed in order to explain how genetic and non-genetic elements affect the determination of handedness. In the past decades, the genetic models of Annett (1972, 1985, 1999, 2002) and McManus (1985, 1999, 2002) had prevailed. These models suggest that the variation observed in handedness (i.e., the fact that not all individuals are right-handed or left-handed) can be attributed to a heterozygote advantage in cognition. According to Annett (1985), heterozygotes will be moderately right-handed with optimal brain organization and enhanced cognitive abilities. However, those who are homozygous might be either strongly left- or strongly right-handed (depending on the allele they are homozygous for) and will tend to present cognitive deficits. McManus et al. (2013) also claim that heterozygotes could have greater fitness, possibly due to processing advantages that are conferred when cognitive modules that are typically in different hemispheres are collateralized within a hemisphere. Nicholls et al. (2010) have provided support for a heterozygote model, by testing a large participant sample (n = 825) who completed a general cognitive ability (GCA) scale and tests of hand preference and performance. They indeed found that moderate right-handers (for performance, not preference measures) had higher GCA scores compared to strong left- or strong right-handers, even though differences were very small in magnitude.

Of note, both Annett's and McManus's models refer to hypothetical genes that might correspond not to a single gene, but to a group of genes (McManus et al., 2013). Indeed, recent genetic studies have shifted to a multifactorial rather than a monogenic approach (Francks et al., 2002; Mc Manus et al., 2013; Piper et al., 2013; Scerri et al., 2011, Van Agtmael et al., 2002; for a review see Ocklenburg et al., 2013). These studies, which are predominantly large-scale twin studies and genome-wide association studies (GWAS), have indicated additive genetic effects, as they have failed to report significant single nucleotide polymorphisms for left-handedness (e.g., Armour et al., 2014; Eriksson et al., 2010; McManus, et al., 2013; Medland et al., 2009; Vuoksimaa et al., 2009). For example, McManus et al. (2013) conducted a GWAS analysis in 3750 individuals, which led to the conclusion that handedness is not controlled by a single genetic locus, but is probably the combined effect of nearly 40 genes. Tentative associations of left-handedness with the following genes have been suggested to date: AR, COMT, PCSK6, and LRRTM1 (Brandler et al., 2013; Francks et al., 2007; Medland et al., 2005; Ocklenburg et al., 2015; Savitz et al., 2007; Scerri, et al., 2011).

Satz has made the case for "pathological" left-handedness, suggesting that left-handedness can be attributed to brain damage in the left cerebral hemisphere prenatally or perinatally (Satz, 1972; Satz et al., 1985). According to this model, lower cognitive abilities and left-handedness result independently from brain damage. The case of brain damage could not be the case for all left-handers, but it could be the element that distinguishes "normal" from "pathological" left-handers. Indeed, connections between an increased incidence of non-right-handedness and various developmental disorders, such as autism, Down's syndrome, and epilepsy have been reported (Forrester et al., 2014; Lewin et al., 1993; Lindell and Hudry, 2013; Markou et al., 2017). However, the concept of "pathological" left-handedness is not entirely uncontroversial (McManus, 1983; Harris and Carlson, 1988).

It could be possible that both the cognitive deficits and the cognitive benefits that have been reported can be explained by a wider distribution of cognitive ability for left-handers. For example, Nicholls et al. (2010) attempted to explain the over-representation of the left- and mixed-handers in intellectually disabled and gifted individuals, using the "crowding hypothesis". According to this theory, left- and mixed-handedness might reflect a shift in the typical pattern of left-hemisphere cerebral laterality of language and hand control to the right hemisphere, at least for a proportion of left- or mixed-handers. This re-organization of cognitive functions could be either beneficial (Benbow, 1986) or harmful to cognitive ability (Lidzba et al., 2006). In other words, the shift of cognitive functions could lead them to better interact with other functions or could lead them to compete for the same neural space, resulting in "cognitive crowding" and cognitive impairments. Nevertheless, an over-representation of left-handers in gifted individuals has not been confirmed to date. On the contrary, gifted individuals have been found in a recent meta-analysis to have less chances of being left-handed compared to the general population, but the same chances of being non-right-handed (Papadatou-Pastou and Tomprou, 2015). However, the literature on handedness in gifted individuals is scarce, as evidenced by the fact that only six studies were included in the Papadatou-Pastou and Tomprou (2015) meta-analysis.

1.4. Scope of the present study

Overall, the question of whether left-handedness conveys cognitive advantages or disadvantages remains unclear. A systematic review and meta-analysis of the literature could help shed light on this question. A systematic review differs from a narrative review in that the studies to be reviewed are collected using clearly defined criteria, thereby overcoming the subjectivity of conventional reviews. A meta-analysis takes the systematic collection of previous work one step further and refers to the statistical synthesis of the effect sizes reported in previous studies, a synthesis that takes into account the sample size and hence accuracy of each study, giving different weights to each study in the overall analysis. Furthermore, meta-analytic techniques allow for publication bias to be detected and heterogeneity among studies to be estimated. In cases of heterogeneity, moderator variables can be detected (Egger and Smith, 1997; Rosenthal and DiMatteo, 2001; Walker et al., 2008).

The present study is a systematic review of the literature on handedness and intelligence with the aim to answer the question of whether different handedness groups differ with regards to their IQ scores. We focus on studies that report full IQ scores; studies that report verbal and non-verbal scores separately, but which nevertheless provide enough information to combine these scores into an overall score (e.g., Gibson, 1973; Newcombe and Ratcliff, 1973), are also within our scope. In order to further test the statistical significance and quantify the differences in IQ score between handedness groups, a meta-analysis of all studies that lend themselves to this statistical technique (i.e., report mean IQ scores and standard deviations for each handedness group) was conducted. The meta-analysis included three sets of analyses contrasting (i) left- and right-handers, (ii) non-right- and right-handers, and (iii) mixed- and right-handers. Furthermore, the meta-analysis aims to estimate possible heterogeneity among studies and investigate the presence of moderators. The potential moderating effect of the following variables was tested: year of publication, classification of handedness groups, intelligence measurement, and participants' sex.

Last but not least, the present study assesses whether publication bias has affected the reported relationship between handedness and intelligence.

2. Method

In order to identify the studies included in the systematic review and the meta-analysis, we conducted a systematic research in the online databases Pubmed MEDLINE at PUBMED (NLM), PsychINFO, and Scopus. Combinations of the following search terms were used: “handedness”, “hand skill”, and “hand preference” and “IQ” and “intelligence”. Data collection ended in February 2016. The cited literature of all articles that were eligible for inclusion was scanned and their references for pertinent articles were searched as well. In addition, we sent an e-mail request for unpublished data to the authors of the articles, in order to ensure that no pertinent study, published or unpublished, had been overlooked. Thirty-six studies were included in the systematic review and 18 studies in the meta-analysis.

2.1. Study selection

Inclusion in the systematic review of studies on handedness and intelligence was subject to the following constraints:

a) To be considered for inclusion, a study had to report IQ data using a standardized test of full IQ (e.g., WISC, WAIS, Raven test). Consequently, studies not measuring participants’ general IQ, but rather individual abilities, such as verbal/spatial ability or reading achievement were excluded (e.g., Burnett et al., 1982; Johnson and Harley, 1980; Palmer and Corballis, 1996; Snyder and Harris, 1993).

b) Studies had to report IQ data on at least two handedness groups. Studies assessing intelligence in a sample of left-handers or right-handers exclusively were not included (e.g., Miller, 1971; Tan, 1989).

c) All studies were required to provide data on healthy participants. Studies in which participants were reported to suffer from a specific condition or disorder (dyslexia, autism, ADHD, Down syndrome, schizophrenia, epilepsy, etc) were not included (e.g., Barry and James, 1978; Deep-Soboslay et al., 2010; Forrester et al., 2014; Lewin et al., 1993).

d) Studies whose participants were selected on the basis of their IQ, for example gifted or intellectually disabled participants, were excluded (e.g., Aliotti, 1981; Barry and James, 1978; Piro, 1998).

e) Reports had to be written in English or Greek.

In order for the data sets to be included in the meta-analyses, they needed to report usable arithmetic data. Studies for which IQ means and standard deviations could not be calculated, were not included in the meta-analysis, but were only included in the systematic review. It should be noted that in some cases IQ data were combined for the purposes of the meta-analysis by the present authors (Annett and Turner, 1974; Bishop, 1980; Fagan-Dubin, 1974; Gibson, 1973; Hicks and Beveridge, 1978; Inglis and Lawson, 1984; Mascie-Taylor, 1980; McManus and Mascie-Taylor, 1983; Newcombe and Ratcliff, 1973; Newcombe et al., 1975; Nicholls et al., 2010; Ounsted et al., 1985; Sherman, 1979; Witelson et al., 2006). Details about the method of literature search and study selection are shown in Fig. 1.

Please insert Figure 1 about here

2.2. Moderators

The categorical and interval variables whose possible effects were examined in the meta-analysis included the following:

2.2.1Year of publication

For investigating possible moderation in terms of secular change, the year of publication was entered numerically for each study.

2.2.2 Classification of handedness groups

The classification of handedness in the studies that were included in the meta-analysis followed either a binary classification with two handedness classes (RH-LH or Consistent RH-non Consistent RH; e.g., Witelson et al., 2006) or a classification with three (RH-MH-LH) or more handedness classes (LH-ML-MR-RH; e.g., Annett and Turner, 1974, L-L/E-R/L/E/-R/L-R/E-R; e.g., Newcombe et al., 1975). The studies were coded for classification of handedness using two different groupings: a) studies with two handedness classes and b) studies with three or more handedness classes. In the case of the Newcombe et al.'s study (1975) the intermediate classes were grouped to form the mixed-handedness class for the purposes of the meta-analysis. The same procedure was followed in the case of the Annett and Turner (1974) study, where the mixed-left- and the mixed-right-handers were considered to be one class, the mixed-handers.

2.2.3 Subdivision by sex

To investigate the possible effect of sex on the relationship between hand preference and intelligence, we performed separate meta-analyses on the studies reporting data separately for males and females (e.g., Witelson et al., 2006). Only 11 out of the 18 studies provided such information and all 11 studies used a binary classification of handedness.

2.2.4 Intelligence measurement

Intelligence was measured by the Wechsler Intelligence Scale for Children (WISC; Wechsler, 1974) or the Wechsler Adult Intelligence Scale (WAIS or WAIS-

R) in 10 out of 18 cases, representing the first level of this variable. In the remaining eight studies, the IQ tests comprised a battery of mental tests (e.g., British Ability Scales, Culture Fair Intelligence Test, Raven test, Stanford Achievement Test). These eight studies, which could not be further categorized due to lack of sufficient data points, represented the second level of this variable.

Some further variables with a possible moderating effect were not examined due to missing or unusable data (e.g., instrument used to measure handedness, age, as well as whether hand preference or hand skill was assessed).

2.3. Statistical analysis

Three separate meta-analysis sets were performed contrasting (i) left- and right-handers, (ii) non-right- and right-handers, (iii) mixed- and right-handers. Left-handers were either (i) the participants classified as left-handers in the binary classifications (RH-LH) or as non-consistent right-handers in the case of Witelson et al.'s study (2006) or (ii) the participants at the left-extreme of three-way (RH-MH-LH) or more (RH-MR-ML-LH, L-L/E-R/L/E-R/L-R/E-R) classifications. Non-right-handers were either (i) the participants classified as left-handers in the studies using binary classifications or (ii) the participants that were classified as left-extreme, non-consistent left-handers or mixed-handers. Mixed-handers were either (i) the participants classified as mixed-handers in the three-way classifications or (ii) the combination of the intermediate groups in the studies using more than three handedness groups (e.g., right-mixed-handers and left-mixed-handers combined; Annett and Turner, 1974). The software package Comprehensive Meta-Analysis (v. 2; Borenstein et al., 2005) was used for data analysis.

The standardized difference in means between the two handedness groups studied in each comparison was used as the effect size measure. Firstly, an effect size was calculated for each data set independently with its corresponding 95% confidence interval. Then, an overall estimation of the effect size across studies was calculated and weighted according to sample size, using a fixed-effects model along with a test for the overall effect (Z statistic). The fixed effects model assumes that all the data sets come from a single population; it asks what the best estimate of the effect size is. The effect sizes were tested to see if they come from a single population using two tests of homogeneity, the Q statistic and the I^2 index. I^2 index levels of 25%, 50%, and 75% may be described as low, moderate, and high, respectively (Higgins et al., 2003). In the case of significant heterogeneity between the studies, the overall effect size was calculated again using a random effects model. The random effects model assumes that the data sets are drawn from a distribution of populations and asks what the range of the effect sizes of the populations studied is. This meta-analytic procedure is known as the “conditionally random-effects” procedure (Hedges and Vevea, 1998). Forest plots were used to depict the information visually.

In the case of significant heterogeneity the presence of moderator variables was also investigated. To test for the possible moderating effect of the interval moderator variable (i.e., year of publication) meta-regression was used. Meta-regression is similar in essence to regression: the moderator variable is predicted according to the weighted effect size of each data set. Random effects models were used as recommended by Thompson and Higgins (2002), with evaluation in terms of the Q statistic. In examining the effects of the categorical moderator variables (i.e., classification of handedness and instrument used to measure intelligence) the average effect sizes in the different subgroups that form the levels of the moderator were compared again by means of the Q statistic. The data sets of studies that reported data separately for males and females were analyzed using a within-study design, to investigate the possible moderating effect of sex.

The studies were also tested for possible publication bias, which can exist when significant results are produced by non-random sampling of the data-sets (i.e., when studies that do not produce the expected effect remain unpublished), using the funnel plot graphical test and Egger's *t* statistical test. Duval and Tweedie's (2000) trim and fill method of correcting bias was also used. The latter is a nonparametric method, using simple rank-based data augmentation techniques, for estimating the number of missing studies that might exist in a meta-analysis and the effect that these studies might have had on its outcome.

3. Results

3.1. Systematic review

A total of 36 studies were included in the systematic review, totaling 66,108 individuals. Eighteen of the 36 studies reported usable arithmetic data, therefore they were also entered in the meta-analyses described below (see section 3.2). The details of all the studies included in the systematic review can be found in Table 1. In four cases (Koufaki, 2014; McManus and Mascie-Taylor, 1983; Nicholls et al., 2012; Tomprou, 2013), raw data were kindly provided by the original authors. Three of the studies included in the systematic review (Crow et al., 1998; McManus and Mascie-Taylor, 1983; Nettle, 2003) used the same database (National Child Development Study). In the meta-analysis, the results are registered only once, using the McManus and Mascie-Taylor's data.

Please insert Table 1 about here

As can be seen in Table 1, 18 studies reported no significant difference in IQ scores between left- and right-handers (Annett and Turner, 1974; Bishop, 1980; Caplan and Kinsbourne, 1981; Douglas et al., 1967; Fagan-Dubin, 1974; Gibson, 1973; Hardyck et al.,1976; Inglis and Lawson, 1984; Keller et al., 1973; Koufaki, 2014; Mascie-Taylor, 1980; McManus et al., 1988; Newcombe and Ratcliff, 1973; Orme, 1970; Sherman, 1979; Tomprou, 2013; Wilson and Dolan, 1931; Witelson et al., 2006). Nine studies reported significantly higher IQ scores in favor of right-handers (Bradshaw et al., 1981; Briggs et al., 1976; Calnan and Richardson, 1976; Hicks and Beveridge, 1978; Levy, 1969; McManus and Mascie-Taylor, 1983; Nicholls et al., 2010; Nicholls et al., 2012; Resch et al., 1997). Five studies reported elevated levels of IQ scores in left-handers compared to right-handers (Annett and Manning, 1989; Ghayas and Adil, 2007; Heim and Watts, 1976; Levander et al., 1989; Ounsted et al., 1985). Three studies (Corballis et al., 2008; Crow et al., 1998; Nettle, 2003) claimed deficits linked to the point of laterality indecision, while only one study (Newcombe et al., 1975) suggested an increased level of cognitive ability in mixed-handedness. Table 2 presents the instruments used to measure intelligence and their relationship to handedness. Table 3 presents the classification of handedness used in studies and groups their findings.

Please insert Tables 2-4 about here

Table 4 presents the participants' age in the different studies and groups their findings. Twenty out of the 36 studies included in the systematic review had a sample of children up to 18 years old (Annett and Manning, 1989; Annett and Turner, 1974; Bishop, 1980; Calnan and Richardson, 1976; Caplan and Kinsbourne, 1981; Crow et al., 1998; Douglas et al., 1967; Fagan-Dubin, 1974; Hardyck et al., 1976; Keller et al., 1973; Koufaki, 2014; McManus and Mascie-Taylor, 1983; McManus et al., 1988; Nettle, 2003; Nicholls et al., 2012; Orme, 1970; Ounsted et al., 1985; Sherman, 1979; Tomprou, 2013; Wilson and Dolan, 1931). Thirteen out of these 20 studies reported no significant difference in IQ scores between left- and right-handers (Annett and Turner, 1974; Bishop, 1980; Caplan and Kinsbourne, 1981; Douglas et al., 1967; Fagan-Dubin, 1974; Hardyck et al., 1976; Keller et al., 1973; Koufaki, 2014; McManus et al., 1988; Orme, 1970; Sherman, 1979; Tomprou, 2013; Wilson and Dolan, 1931), three indicated higher IQ scores for right-handers compared to left-handers (Calnan and Richardson, 1976; McManus and Mascie-Taylor, 1983; Nicholls et al., 2012), two supported the superiority of the left-handers (Annett and Manning, 1989; Ounsted et al., 1985) and two (Crow et al., 1998; Nettle, 2003) claimed deficits for mixed-handedness (though both studies used the same database, namely the National Child Development Study database).

Even though it was out of the scope of the present analysis to study the effect of sex on intelligence scores, it might be worth mentioning that eight studies reported no significant difference in intelligence scores between males and females (Briggs et al., 1976; Keller et al., 1973; Mascie-Taylor, 1980; McManus et al., 1988; Newcombe and Ratcliff, 1973; Resch et al., 1997; Tomprou, 2013; Witelson et al., 2006). Three studies claimed that females scored higher on intelligence tests, one of which (Wilson and Dolan, 1931) referred to all of the intelligence tests used, whereas the other two studies (Caplan and Kinsbourne, 1981; Crow et al., 1998) referred only to verbal IQ. Six studies reported males' superiority in IQ scores, three of which (Inglis and Lawson, 1984; Newcombe et al., 1975; Nicholls et al., 2010) found this difference for all of the intelligence tests used, two (Heim and Watts, 1976; Sherman, 1979) referred to numerical tests and one (Nicholls et al., 2012) referred to vocabulary tests. Three studies (Annett and Manning, 1989; Fagan-Dubin, 1974; McManus and Mascie-Taylor, 1983) reported that females scored higher on verbal IQ tests than males, but at the same time males scored higher on performance IQ tests.

It is interesting to observe that in a few of the oldest studies (Douglas et al., 1967; Hardyck et al., 1976; Wilson and Dolan, 1931) left-handedness is treated as a matter of social concern due to the social pressure exerted to the left-handers to convert their handedness direction. As a result, authors expressed their doubts on whether left-handers are classified correctly or whether they have been wrongly registered as right-handers. This concern is not mentioned in more recent studies.

3.2. Meta-Analyses

A total of 18 studies were included in the analyses, totaling 20,44 individuals (17,518 right-handed individuals). The details of all the studies used can be found in Table 1. Three sets of meta-analyses were conducted contrasting (i) left- and right-handers, (ii) non-right- and right-handers, (iii) mixed- and right-handers.

3.3. Results of the left-handedness comparison

3.3.1 Overall results

Only for two out of the 18 data sets included in this analysis was the standardized difference in means statistically significant (Ghayas and Adil, 2007; McManus and Mascie-Taylor, 1983). Fixed effects analysis gave a pooled standardized difference in means of d = -0.07, 95% CI = -0.12, -0.03, Z = -3.09, p = 0.002 (see Fig. 2). The heterogeneity among the data sets was not found to be significant, Q (17) = 16.12, p = 0.52, with no inconsistency between studies, I^2 =0.00%, thus a further analysis based on the random effects model was not necessary. Moreover, since under the fixed effect model all data sets describe a single population, no moderator variables analysis was granted here. The results show that right-handed individuals tend to present higher intelligence scores compared to left-handed individuals, albeit the absolute difference in scores is minute.

Please insert Figure 2 about here

Due to the large sample size of one study (n = 12,779 individuals; McManus and Mascie-Taylor, 1983), a further analysis was conducted without this study. The comparison included k = 17 studies adding up to n = 7,663 individuals (n = 6,185 right-handed individuals). Fixed effects analysis gave a pooled standardized difference in means of d = -0.02, 95% CI = -0.10, 0.06, Z = -0.48, p = 0.63. The heterogeneity among the data sets was not found to be significant, Q (16) = 13.78, p = 0.61, with no inconsistency between studies, I^2 = 0.00%, thus a further analysis based on the random effects model was not necessary. The results again show that right-handed individuals tend to present higher intelligence scores compared to left-handed individuals, but this difference is not statistically significant.

3.3.2 Sex differences in left-handedness

A further meta-analysis, which aimed to examine the possible sex effect on the relationship between hand preference and intelligence, was conducted including only the studies that broke down their data in males and females (Koufaki, 2014, only included one female participant, so only the data on males were used). Eleven out of the 18 studies were included, totaling 17,875 individuals (1,142 left-handed males, 837 left-handed females, 7,869 right-handed males, 8,027 right-handed females) (Fagan-Dubin, 1974; Inglis and Lawson, 1984; Koufaki, 2014; Mascie-Taylor, 1980; McManus and Mascie-Taylor, 1983; Newcombe and Ratcliff, 1973; Newcombe et al., 1975; Nicholls et al., 2010; Sherman, 1979; Tomprou, 2013; Witelson et al., 2006). All studies used a binary classification of handedness. The pooled effect sizes of the subgroups of the studies that represented male participants were compared with the pooled effect sizes of the subgroups of the studies that represented the female participants and no significant sex effect on the relationship between hand preference and intelligence was detected, Q (1) = 0.02, p = 0.89 (see Fig. 3).

Please insert Figure 3 about here

3.3.3 Publication bias

The data sets that were included in the left-handedness comparison were then tested for publication bias. Publication bias was not detected using Egger's Test, t (16) = 1.06, p = 0.31. However, visual inspection of the funnel plot graphical test did provide some evidence of asymmetry and hence possible publication bias (see Fig. 4). Using Duval and Tweedie's trim and fill method for bias correction for the fixed effects model two data sets were "filled" in the left side of the funnel, which represents higher intelligence scores for right-handers compared to left-handers. An adjusted standardized difference in means was calculated, d = -0.08, 95% CI = -0.13, -0.04.

Please insert Figure 4 about here

3.3.4 Summary of results

Left-handers and right-handers were found to differ in their intelligence scores. The standardized difference in means was very small, d = - 0.07, yet statistically significant, $p = 0.002$. The difference was no longer significant when the largest study was excluded from the analysis (McManus and Mascie-Taylor, 1983). No sex difference was found in the relationship between intelligence and hand preference. Publication bias was found only using Duval and Tweedie's trim and fill method, which indicated that two studies showing higher IQ scores for right-handers are missing, which would make the standardized difference in means $d = -0.08$, 95% CI = -0.13, -0.04.

3.4. Results of the non-right-handedness comparison

3.4.1 Overall results

For three out of the 18 data sets included in this analysis was the standardized difference in mean statistically significant (Ghayas and Adil, 2007; Mascie-Taylor, 1980; McManus and Mascie-Taylor, 1983). Fixed effects analysis gave a pooled standardized difference in means of $d = -0.06$, 95% CI = -0.10, -0.02, $Z = -2.84$, $p = 0.005$. The heterogeneity among the data sets was found to be significant, Q (17) = 29.96, $p = 0.027$, with moderate inconsistency between studies, $I^2 = 43.26\%$. The random effects model was thus employed, which gave a non-significant standardized difference in means of $d = -0.03$, 95% CI = -0.11, 0.05, $Z = -0.78$, $p = 0.43$ (see Fig. 5).

Please insert Figure 5 about here

As with the left-handedness comparison, a further analysis was conducted without the study of McManus and Mascie-Taylor (1983), due to its large sample size (n = 12,779 individuals). Fixed effects analysis gave a pooled standardized difference in means of $d = -0.01$, 95% CI = -0.08, 0.05, $Z = -0.41$, $p = 0.68$. The heterogeneity among the data sets was found to be marginally significant, $Q\,(16) = 26.19$, $p = 0.051$, with moderate inconsistency between studies, $I^2 = 38.92\%$. A random effects model was therefore employed, which gave a non-significant standardized difference in means of $d = -0.02$, 95% CI = -0.11, 0.07, $Z = -0.43$, $p = 0.67$. The results again show that right-handed individuals tend to present higher intelligence scores compared to non-right-handed individuals, but this difference is not statistically significant.

3.4.2 Sex differences in non-right-handedness

A further meta-analysis which aimed to examine the possible sex effect on the relationship between non-right hand preference and intelligence included only the studies that broke down their data in males and females. Eleven out of the 18 studies were included, totaling 18,469 individuals (1491 non-right-handed males, 1082 non-right-handed females, 7869 right-handed males, 8027 right-handed females) (Fagan-Dubin, 1974; Inglis and Lawson, 1984; Koufaki, 2014; Mascie-Taylor, 1980; McManus and Mascie-Taylor, 1983; Newcombe and Ratcliff, 1973; Newcombe et al., 1975; Nicholls et al., 2010; Sherman, 1979; Tomprou, 2013; Witelson et al., 2006). Again, only males were included from the Koufaki 2014 study. All studies used a binary classification of handedness. The pooled effect sizes of the subgroups of studies that represented male participants were compared with the pooled effect sizes of the subgroups of the studies that represented the female participants and no significant sex effect on the relationship between hand preference and intelligence was detected, $Q\,(1) = 0.04$, $p = 0.84$ (see Fig. 6).

Please insert Figure 6 about here

3.4.3 Moderating variables

Because of the moderate inconsistency detected among studies, the possible moderating effects of the year of publication, classification, and the instrument used to measure intelligence were tested within the non-right-handedness comparison. A meta-regression of the year of publication of the studies was conducted, but did not reveal a significant linear trend on the size of the standardized differences in means, Q (1) = 0.23, p = 0.63. No significant moderating effects were found for the classification of handedness, Q (1) = 0.71, p = 0.40, and the instrument used to measure intelligence, Q (1) = 0.01, p = 0.93.

3.4.4 Publication bias

The data sets that were included in the non-right-handedness comparison were then tested for publication bias. Publication bias was not detected using Egger's Test, t (16) = 0.69, p = 0.50. (see Fig. 7). Using Duval and Tweedie's trim and fill method for bias correction for the random effects model, three data sets were "filled" in the right side of the funnel, which represents higher intelligence scores for non-right-handers compared to right-handers. An adjusted standardized difference in means was calculated, d = -0.01, 95%, CI = -0.09, 0.06.

Please insert Figure 7 about here

3.4.5 Summary of results

Right-handers and non-right-handers were not found to differ in their intelligence scores. No sex difference was found in the relationship between intelligence and hand preference. No variables were found to moderate these effects. Publication bias was found to exist using Duval and Tweedie's trim and fill method, which indicated that three studies showing higher IQ scores for non-right-handers are missing, which would make the standardized difference in means d = -0.01, 95% CI = -0.09, 0.06.

3.5. Results of the mixed-handedness comparison

3.5.1 Overall results

Only four out of the 18 studies provided information about mixed-handers and were therefore included in this analysis (Annet and Turner, 1974; Mascie-Taylor, 1980; Newcombe and Ratcliff, 1973; Newcombe et al., 1975). Fixed effects analysis gave a pooled standardized difference in means of d = 0.00, 95% CI = -0.09, 0.09, Z = 0.01, p = 0.99. The heterogeneity among the data sets was found to be significant, Q (3) = 16,43, p = 0.001, with high inconsistency between studies, I^2 = 81.74%. A random effects model was therefore employed, which gave a non-significant standardized difference in means of d = 0.02, 95% CI = -0.21, 0.24, Z = 0.16, p = 0.87 (see Fig. 8).

Please insert Figure 8 about here

3.5.2 Sex differences in mixed-handedness

A further meta-analysis, which aimed to examine the possible sex effect on the relationship between mixed hand preference and intelligence, included only the studies that broke down their data in males and females. Three out of the four studies were included, totaling 2339 individuals (349 mixed-handed males, 245 mixed-handed females, 810 right-handed males, 935 right-handed females) (Mascie-Taylor, 1980; Newcombe and Ratcliff, 1973; Newcombe et al., 1975). The pooled effect sizes of the subgroups of studies that represented male participants were compared with the pooled effect sizes of the subgroups of the studies that represented the female participants and no significant sex effect on the relationship between mixed hand preference and intelligence was detected, Q (1) = 0.16, p = 0.69.

3.5.3 Summary of results

Right-handers and mixed-handers were not found to differ statistically significantly in their intelligence scores, d = 0.02, p = 0.87. No sex difference was found in the relationship between intelligence and mixed hand preference. Due to the small number of studies included in this comparison, moderating variables and publication bias analyses were not justified.

4. Discussion

A systematic review was conducted in order to summarize efficiently the results of the studies on intelligence in different handedness groups. A total of 36 studies were included, totaling 66,108 individuals. Three sets of meta-analyses on 18 studies, totaling 20,442 individuals, were also conducted using the sub-set of the studies included in the systematic review that provided means and standard deviations of IQ scores for each handedness group. The meta-analyses investigated possible differences in standardized IQ score means in (i) left-handers compared to right-handers, (ii) non-right-handers compared to right-handers, and (iii) mixed-handedness compared to right-handers. Possible sex differences were also investigated, along with moderating variable and publication bias analyses.

The findings of the systematic review were inconclusive, yet heavily skewed towards no differences in IQ scores between left- and right-handers. Specifically, it was shown that 18 out of the 36 included studies reported no significant difference in IQ scores between left- and right-handers, nine studies reported significantly higher IQ scores in favor of right-handers and five studies reported elevated levels of IQ scores in left-handers compared to right-handers. Three studies claimed deficits linked to weak hand preference, while one study suggested increased level of cognitive ability in mixed-handedness.

The meta-analysis revealed that right-handers have higher mean IQ scores compared to left-handers. This difference was statistically significant, however, the absolute difference in means was only marginal (d = -0.07). As an illustration, if the mean IQ score of a group of 100 left-handers were exactly 100 with a standard deviation of 15, the mean IQ score for a group of 100 right-handers would be 101.05 (if the standard deviation was again 15). When the largest study (McManus and Mascie-Taylor 1983) was excluded, the pooled standardized difference in means became even smaller (d = - 0.02) and lost statistical significance. The difference in mean IQ scores between right-handers and non-right-handers as well as right-handers and mixed-handers was not found to be statistically significant. No sex difference was found to moderate the relationship between intelligence and handedness. Tests of publication bias revealed that there was no evidence that the studies in the sample had been distorted by preferential reporting, when using Egger's t test. Using Duval and Tweedie's trim and fill method, two studies showing higher IQ scores for right-handers that would make the standardized difference in means d = -0.08, 95% CI = -0.13, -0.04, were found to be missing from the left-handedness comparison.

The marginally higher mean IQ scores of right-handers compared to those of left-handers that were found in the present study could be explained by the findings of two recent meta-analyses. Papadatou-Pastou and Tomprou (2015) included in their analyses the studies that have compared intellectually gifted individuals to typically developing individuals in terms of handedness and found that gifted individuals are less prone to left-handedness compared to typically developing individuals, with a ratio of gifted individuals to typically developing individuals left-handedness odds of 0.76. Thus, if the prevalence of left-handedness in typically developing individuals were exactly 10%, the observed estimate of 0.76 would be equivalent to a prevalence of intellectually gifted left-handedness of 7.79%. Somers et al. (2015), in their meta-analysis on the cognitive benefits of right-handedness, found a small but significant effect favoring right-handedness for overall spatial ability, but no difference between left- and right-handers for verbal ability. Therefore, the slight advantage in mean IQ scores for right-handers that was found in the present study could possibly be attributed either to the fact that gifted individuals are being overrepresented among the population of right-handers or to the better spatial abilities of right-handers compared to left-handers.

It could be argued further that the present findings are skewed by left-handers whose laterality is pathological in origin and who thus score lower than their counterparts whose left-handedness is due to normal variation. Annett and Turner (1974), for example, have argued that left-handers are overrepresented at the lower extreme of the ability distribution. However, we do not expect pathological left-handedness to have had a significant effect on the present findings, based on the findings of McManus and Mascie-Taylor (1983) who analyzed official data from 13,808 children derived from the National Child Development Study, both including the whole sample of 11-year olds and removing the participants with the 5% lowest scores from their analysis (n=12,779). In both cases their findings remained the same, namely they found that left-handers scored statistically significantly lower on g than right-handers.

The present findings pose a serious question to the hypothesis claiming that atypical-handedness is associated with cognitive deficits (Briggs et al., 1976; Nicholls et al., 2010, 2012). It also casts doubts to the exact opposite suggestion that atypical-handedness is associated with elevated cognitive functioning (McManus, 2002). Last but not least, it does not provide support for suggestions that have been made about deficits at the point of hemispheric indecision (Crow et al., 1998; Corballis et al., 2008), even though degree of handedness was not analyzed per se and the conclusion draws merely from the mixed-handedness comparison, which only included four studies.

The meta-analysis presents with a number of limitations. First of all, many studies have been excluded due to the lack of usable arithmetic data (e.g., Nicholls et al., 2012; McManus et al., 1988). The systematic review partially solves this problem, however, lacks in accuracy, as it is not a statistical synthesis of effect sizes, and it can only provide descriptive findings. A systematic review cannot weight the contribution of each study's findings according to its sample size, cannot explore the presence of heterogeneity, test for the presence of possible moderator variables, or investigate the presence of publication bias.

Secondly, the relationship of intelligence scores with degree of handedness was not investigated, as only three studies (Caplan and Kinsbourne, 1981; Crow et al., 1998; Mc Manus et al., 1988) have reported on the possible intelligence differences between individuals with weak versus strong hand preference, with Caplan and Kinsbourne (1981) not providing numerical data. For the bulk of the studies included in the meta-analyses, the participants were grouped in handedness groups according to direction of hand preference by the original authors and no information on degree was reported. Therefore, the meta-analyses had to employ the same handedness groups as those reported in the original studies before their differences in mean IQ scores were compared, as systematic reviews and meta-analyses by definition rely on previously conducted research. It could be the case that the results of the meta-analysis would had been different if participants were grouped in terms of degree of handedness (i.e., in individuals with weak versus strong preference), as there is literature suggesting that it is the degree rather than the direction of handedness that relates to intelligence (e.g., Corballis et al., 2008; Crow et al., 1998; Nettle, 2003). Moreover, it has been suggested that degree of handedness may be a better indicator of underlying brain pathology and/or psychological abnormalities than direction of handedness (Crow et al., 1998; Nicholls et al., 2005). It is strongly recommended that future studies on the relationship between handedness and intelligence report the degree of handedness in addition to its direction.

There are two distinctive ways of measuring handedness: hand preference and relative hand skill. It has been shown, though, that these two elements correlate reliably to each other, albeit not perfectly (0.6-0.7; Todor and Doane, 1977). The imperfect correlation can be attributed to the relatively unreliable measurement of relative hand skill (Hiscock and Chapieski, 2004) as well as to the difference in distributions between preference and skill measures (negatively skewed and normal, respectively). However, an analysis of IQ differences in handedness as assessed by hand skill was not feasible within the present study. Even though hand skill was reported in several cases along with hand preference scores, in a number of them no information was given with regards to the relationship of hand skill and intelligence scores (Annett and Turner, 1974; Bishop, 1980; Bradshaw et al., 1981; Calnan and Richardson, 1976), while in the remaining studies the results were presented in such varied formats, that a uniform effect size could not be calculated for all of them in order for a meta-analysis to be feasible (Annett and Manning, 1989; Crow et al., 1998; Koufaki, 2014; Nettle, 2003; Nicholls et al., 2010; Resch et al., 1997; Tomprou, 2013). A second recommendation is therefore here made, for researchers to also measure and report relative hand skill along with the intelligence scores from each hand skill group, in addition to hand preference in their samples.

5. Conclusions

The present study provides a reliable and robust test of the hypothesis that the IQ differences that exist between different handedness groups are negligible; even though statistically significant differences in favour of right-handers were found when right-handers were compared to left-handers, the absolute magnitude of those differences was extremely small. In addition, it was shown that sex does not moderate the relationship between intelligence and hand preference. The jury is still out when it comes to the questions of whether it is degree of hand preference that is associated with intelligence and whether there is a relationship between relative hand skill and intelligence.

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Table 1. Details of studies included in the systematic review and the meta-analyses. (Studies marked with an asterisk (*) indicate studies included in the meta-analysis. In arithmetic data columns (mean IQ scores, standard deviations), combined data were entered instead of separate verbal and visuo-spatial scores, in the cases of studies that did not report combined data.)

Study	*N* (Total)	*N* (Left-handers)	*N* (Mixed-handers)	*N* (Right-handers)	Age (yrs.)	Handedness Instrument	Classification of Handedness	Intelligence Instrument	Data entered into *meta*-analysis		Findings	Notes
									LH: mean IQ score (SD)	RH: mean IQ score (SD)		
* Wilson and Dolan (1931)	975	44	-	931	12	Indication of preferred hand	LH-RH	Battery of IQ tests	102.13 (16.45)	105.45 (15.56)	Left-handers are consistently inferior to the right-handers at the time the children concerned are promoted to the seventh grade. The differences, however, are not statistically reliable.	IQ data not broken down according to sex
Douglas et al. (1967)	3788	227	369	3192	8 - 15	4-item-handedness performance measure	LH-MH-RH	Battery of IQ tests	n/a	n/a	No effect of handedness (small disadvantage for mixed-handers)	Standard deviations could not be calculated
Levy (1969)	25	10	-	15	Graduate students	Not clear	LH-RH	WAIS	n/a	n/a	There is a superiority in favor of the right-handers in performance IQ	Standard deviations could not be calculated
Orme (1970)	300	23	-	277	14 - 17	Indication of preferred hand	LH-RH	Raven	n/a	n/a	No effect of handedness	Means and standard deviations could not be calculated
* Gibson (1973)	145	13	-	132	18+ (Academic scientists)	Not clear	LH-RH	WAIS	123.9 (9.95)	124.45 (8.69)	No effect of handedness	Data were broken down in verbal and visuo-spatial IQ scores and they were combined for the purposes of the *meta*-analysis

												were combined for the purposes of the *meta*-analysis
Keller et al. (1973)	277 (146 males)	128	-	149	Grade 3-12 students	2- item-handedness questionnaire	LH-RH	California Test of Mental Maturity	n/a	n/a	No effect of handedness	Means and standard deviations could not be calculated
* Annett and Turner (1974)	224 (104 males)	37	104	83	5 - 11	5 unimanual tasks, peg moving	LH-ML-MR-RH	Battery of IQ tests	79.52 (44.86)	79.78 (45.74)	No effect of handedness (slight excess of left-handers at the lower extreme of the ability distribution)	Data were broken down in individual ability scores and they were combined for the purposes of the *meta*-analysis. Mixed- left and mixed-right handers were considered to be one class, the mixed-handers. Handedness classes were formed according to hand preference.
* Fagan-Dubin (1974)	46 (29 males)	20	-	26	5 - 6	5-10 battery of handedness tasks	RH-LH	WISC	112.5 (15.71)	114.62 (12.79)	No effect of handedness	Data were broken down in verbal and performance IQ scores and they were combined for the purposes of the *meta*-analysis
* Newcombe et al. (1975)	928 (462 males)	35	154	739	<70	7- item- handedness questionnaire	L-L/E-R/L/E/-R/L-R/E-R	WAIS	106.01 (8.72)	106.37 (12.38)	No effect of handedness (mixed-handers obtained higher IQ scores on verbal tests)	The intermediate classes were grouped to form the mixed-handedness class and the data broken down according to sex were combined for the purposes of the *meta*-analysis
Briggs et al.	204	68	68	68	College	Handedness	LH-MH-RH	WAIS, Kit	n/a	n/a	Left-handers and mixed-	Standard

(1976)	(102 males)				students	questionnaire (Annet, 1970)		of Reference Tests for Cognitive Factors			handers scored lower on ability tests than right-handers	deviations could not be calculated
Calnan and Richardson (1976)	11316	1154	634	9528	11	2-item- handedness observation measure & mother's report, square marking	LH-MH-RH	Tests constructed and standardized by the National Child Development Study	n/a	n/a	Non-right handers had a slight but statistically significant disadvantage on ability tests	Analyses according to hand preference scores. Means and standard deviations could not be calculated.
Hardyck et al. (1976)	7688	741	-	6947	6 - 12	3-item- handedness performance measure	RH-LH	Lorge-Thorndike Intelligence Test	n/a	n/a	No effect of handedness	Standard deviations could not be calculated
Heim and Watts (1976)	2165	203	-	1962	>9	Indication of preferred hand, self-report	RH-LH	Test AH2/3	n/a	n/a	Left-handers (especially males) obtained higher scores on numerical tasks	Standard deviations could not be calculated
* Hicks and Beveridge (1978)	67	30	-	37	College students	Annett's handedness scale (1967)	RH-LH	Culture Fair Intelligence Test, The Cooperative Vocabulary Test (Form 2)	39.1 (17.46)	39.80 (17.10)	Left-handers obtained lower scores on fluid intelligence	Data were broken down in crystallized and fluid intelligence and they were combined for the purposes of the *meta*-analysis
* Sherman (1979)	281 (131 males)	118	-	163	9-11th grade students	14-item hand preference questionnaire	RH-LH	Battery of IQ tests for maths and verbal/spatial performance	49.86 (21.41)	52.05 (20.80)	No significant difference between right-handers and left-handers in the 9th and 10th grade, left-handers obtained higher scores on 11th grade in verbal scores	Data were broken down in verbal, math and spatial scores and they were combined for the purposes of the *meta*-analysis
*Bishop (1980)	170 (78 males)	23	-	147	8 - 9	Writing hand, square tracing task	LH-RH	WISC-R	93.37 (15.69)	97.10 (14.37)	No effect of handedness	Data were broken down in LH and RH according to writing hand and a further two groups according to non-preferred hand

												performance. However, data for all LH and RH were combined for the purposes of the *meta*-analysis
* Mascie-Taylor (1980)	687	38	301	348	>5	7-item- handedness questionnaire	LH-MH-RH	WISC-WAIS	115.45 (7.48)	114.01 (11.95)	No effect of handedness in the left-handedness comparison. In the non-right handedness and mixed-handedness comparisons right-handers obtained higher scores.	Data were broken down in four social groups and they were combined for the purposes of the *meta*-analysis
Bradshaw et al. (1981)	96	48	-	48	>18	Handedness questionnaire, object manipulation procedure, pegboard task	LH-RH	WAIS	n/a	n/a	Left-handers obtained lower IQ scores (biggest differences in performance IQ)	Participants were enrolled only if strongly and consistently right- or left-handed.. Standard deviations could not be calculated
Caplan and Kinsbourne (1981)	105 (52 males)	-	-	-	6 -12	Edinburgh Handedness Inventory	Continuous scores	WISC-R	n/a	n/a	No effect of handedness	Means and standard deviations could not be calculated
* Mc Manus and Mascie-Taylor (1983)	12779 (6540 males)	1446	-	11333	11	National Child Development Study	LH-RH	National Child Developme nt Study	41.89 (16.47)	43.42 (16.00)	Left-handers scored lower on ability tests than right-handers	Calculations based on raw data kindly provided by the original authors
* Inglis and Lawson (1984)	1880 (940 males)	170	-	1710	16 -74	Self-report and indication of preferred hand	LH-RH	WAIS-R	99.98 (15.28)	99.84 (15.17)	No effect of handedness, reliable effect of sex (men scored higher)	Data were broken down in males and females and they were combined for the purposes of the *meta*-analysis
* Ounsted et al. (1985)	242	25	-	217	7.5	Indication of preferred hand	LH-RH	British Ability Scales (BAT)-14 tests, Holborn Reading Scale	58.43 (17.49)	57.49 (16.82)	Left-handers scored higher on 12 out 15 ability tests (BAT)	Data were broken down by IQ subtests and they were combined for the purposes of the *meta*-analysis

Mc Manus et al. (1988)	60	-	-	-	6 -9	10- item- handedness performance measure	Continuous scores	Raven	n/a	n/a	No effect of handedness	Means and standard deviations could not be calculated
Annett and Manning (1989)	342 (169 males)	-	-	-	9 -11	7- item- handedness performance measure, peg moving	LH-RH	Raven	n/a	n/a	The most strongly right-handed children (according to hand skill) scored lower than all others	Means and standard deviations could not be calculated
Levander et al. (1989)	204	102	-	102	College students	Karolinska Hospital hand preference inventory	LH-RH	Battery of IQ tests	n/a	n/a	Left-handers obtained higher scores on visuo-spatial ability	Means and standard deviations could not be calculated
Resch et al. (1997)	545 (265 males)	136	271	138	16 -30	8-item handedness questionnaire, hand dominance test	Continuous scores	Culture Fair Intelligence Test	n/a	n/a	Strong right-handers obtained marginally higher ability scores	Means and standard deviations could not be calculated
Crow et al. (1998)	12770	1437	-	11333	11	National Child Development Study, box ticking	Continuous scores	National Child Developme nt Study (verbal ability \ non verbal ability, reading comprehens ion and mathematic al ability)	n/a	n/a	No significant difference between left-handers and right-handers, but deficits at the point of hemispheric indecision	Means and standard deviations could not be calculated, but the same database as in the Mc Manus' study (1983) was used
Nettle (2003)	8525 (4209 males)	-	-	-	11	National Child Development Study, box ticking	Continuous scores	National Child Developme nt Study (verbal ability \ non verbal ability, reading comprehens ion and	n/a	n/a	Average cognitive ability increases with increasingly strong laterality in either direction	Means and standard deviations could not be calculated

								mathematical ability)				
* Witelson et al. (2006)	100 (42 males)	42	-	58	50 -60	12 unimanual and bimanual tasks (Annett's)	CRH – Non-CRH	WAIS	114.05 (8.39)	116.4 (9.00)	No effect of handedness	Data were broken down in verbal and performance IQ scores and they were combined for the purposes of the *meta*-analysis
* Ghayas and Adil (2007)	150	75	-	75	Intermediate, graduate, post-graduate students	Laterality Assessment Inventory	LH-RH	Raven	44.2 (8.80)	39.8 (12.36)	Left-handers scored higher on ability tests than right-handers	
Corballis et al. (2008)	1353	166	21	1166	18 -60+	Self-report	LH-MH-RH	New Zealand IQ Test	n/a	n/a	Ambidextrous individuals perform more poorly than left- or right-handers, especially on subscales measuring arithmetic, memory, and reasoning	Standard deviations could not be calculated
* Nicholls et al. (2010)	825	68	-	757	17 -50	Handedness questionnaire (Annet1970) and performance (Brain Resource International Database), tapping speed	LH-RH	Brain Resource Cognition battery	103.34 (11.70)	103.99 (12.39)	Greater rightward asymmetry was associated with higher GCA (General Cognitive Ability)	Calculations based on raw data on hand preference kindly provided by the original authors
Nicholls et al. (2012)	17198				5 -10	4-item- handedness performance measure and self-report (British Cohort Study)	LH-RH	British Cohort Study	n/a	n/a	Left-handers scored lower on ability tests than right-handers	Means and standard deviations could not be calculated
* Tomprou (2013)	72	10	-	62	13 -17	Edinburgh Handedness Inventory (EHI), Quantification of hand preference test, peg moving	LH-MH-RH	WISC, Raven	115.40 (11.48)	113.40 (15.69)	No effect of handedness	Calculations based on raw data on hand preference kindly provided by the original authors

* Koufaki (2014)	48	6	-	42	9 -15	Edinburgh Handedness Inventory (EHI), Quantification of hand preference test, peg moving	LH-RH	WISC, Raven	33.17 (5.85)	35.26 (5.72)	No effect of handedness	Calculations based on raw on hand preference data kindly provided by the original authors

Table 2

Intelligence instrument and its relationship to IQ scores.

Intelligence Instrument	**Number of studies**					
	Total	**No effect of handedness on IQ scores**	**Right-handers obtained higher IQ scores**	**Left-handers obtained higher IQ scores**	**Mixed-handers obtained lower IQ scores**	**Mixed-handers obtained higher IQ scores**
WISC/WAIS	12	8	3	0	0	1
Raven	4	2	0	2	0	0
WISC/WAIS/RAVEN	2	2	0	0	0	0
Battery of IQ tests	6	4	1	1	0	0
Other test	7	2	2	2	1	0
Data obtained by a published database	5	0	3	0	2	0

Table 3 Classification of handedness and its relationship to IQ scores.

(LH: Left-handers, RH: Right-handers, MH: Mixed-handers, ML: Moderate Left-handers. MR: Moderate Right-handers, CRH: Consistent Right-handers, Non-CRH: Non-Consistent Right-handers, L-L/E-R/L/E-R/L-R/E-R: six groups of handedness between extreme left-handers and extreme right-handers)

Classification of handedness	**Number of studies**					
	Total	**No effect of handedness in IQ scores**	**Right-handers obtained higher IQ scores**	**Left-handers obtained higher IQ scores**	**Mixed-handers obtained lower IQ scores**	**Mixed-handers obtained higher IQ scores**
LH-RH	21	9	7	5	0	0
LH-MH-RH	7	4	2	0	1	0
LH-ML-MR-RH	1	1	0	0	0	0
L-L/E-R/L/E/-R/L-R/E-R	1	0	0	0	0	1
CRH - Non-CRH	1	1	0	0	0	0
continuous scores	5	2	1	0	2	0

Table 4.

Participants' age and its relationship to IQ scores

Participants' age	**Number of studies**					
	Total	**No effect of handedness on IQ scores**	**Right-handers obtained higher IQ scores**	**Left-handers obtained higher IQ scores**	**Mixed-handers obtained lower IQ scores**	**Mixed-handers obtained higher IQ scores**
Children	20	13	3	2	2	0
Adults	16	5	6	3	1	1

Figure 1 Flow diagram for the search and inclusion criteria for the studies inc the systematic review and meta-analysis. Adapted from "Preferred Reporting for Systematic Reviews and Meta-Analyses: The PRISMA Statement," by D. A. Liberati, J. Tetzlaff, D. G. Altman, and The PRISMA Group, 2009, *PLoS N* *6*(6). Copyright 2009 by the Public Library of Science.

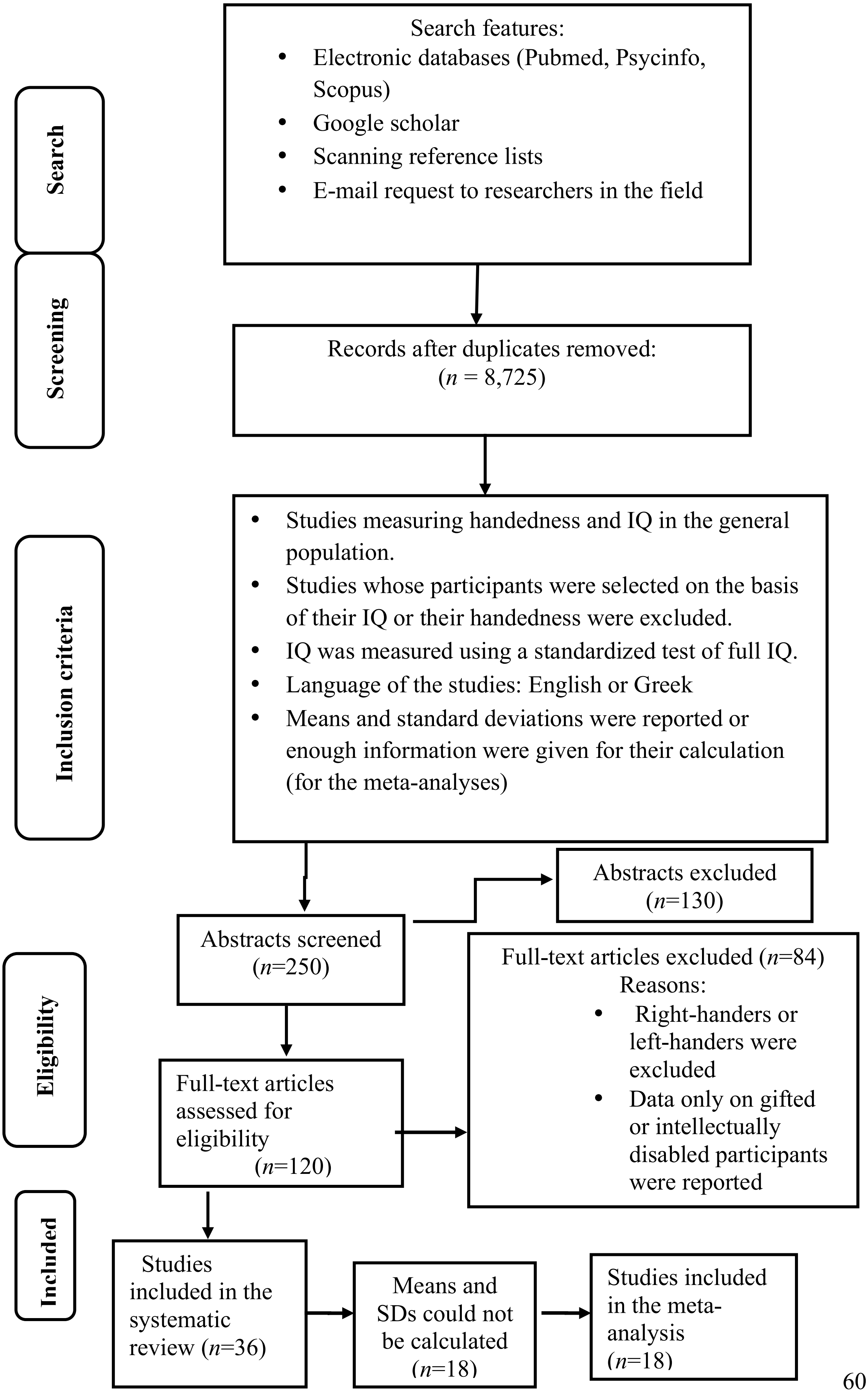
Search
Screening
Inclusion criteria
Eligibility
Included
Search features:
• Electronic databases (Pubmed, Psycinfo, Scopus)
• Google scholar
• Scanning reference lists
• E-mail request to researchers in the field
Records after duplicates removed: (n = 8,725)
• Studies measuring handedness and IQ in the general population.
• Studies whose participants were selected on the basis of their IQ or their handedness were excluded.
• IQ was measured using a standardized test of full IQ.
• Language of the studies: English or Greek
• Means and standard deviations were reported or enough information were given for their calculation (for the meta-analyses)
Abstracts excluded (n=130)
Abstracts screened (n=250)
Full-text articles excluded (n=84)
Reasons:
• Right-handers or left-handers were excluded
• Data only on gifted or intellectually disabled participants were reported
Full-text articles assessed for eligibility (n=120)
Studies included in the systematic review (n=36)
Means and SDs could not be calculated (n=18)
Studies included in the meta-analysis (n=18)

Figure 2 Forest plot of the standardized differences in mean IQ scores between right- and left-handers. In the plot the 95% confidence interval for each study is represented by a horizontal line and the point estimate (Cohen's *d*) is represented by a square. The confidence intervals for the overall mean effect size are represented by a diamond shape at the bottom of the plot.

Study name	Statistics for each study						
	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Wilson & Dolan (1931)	-0.213	0.154	0.024	-0.515	0.090	-1.379	0.168
Gibson (1973)	-0.062	0.291	0.085	-0.632	0.507	-0.215	0.830
Newcombe & Ratcliff (1973)	0.082	0.200	0.040	-0.310	0.474	0.409	0.682
Annett & Turner (1974)	-0.006	0.198	0.039	-0.393	0.382	-0.029	0.977
Fagan-Dubin (1974)	-0.150	0.298	0.089	-0.734	0.434	-0.503	0.615
Newcombe et al. (1975)	-0.029	0.173	0.030	-0.368	0.310	-0.168	0.867
Hicks & Beveridge (1978)	-0.041	0.246	0.060	-0.522	0.441	-0.165	0.869
Sherman (1979)	-0.104	0.121	0.015	-0.341	0.133	-0.859	0.390
Bishop (1980)	-0.256	0.225	0.050	-0.697	0.184	-1.141	0.254
Mascie-Taylor (1980)	0.124	0.171	0.029	-0.211	0.459	0.727	0.467
McManus & Mascie-Taylor (1983)	-0.095	0.028	0.001	-0.150	-0.041	-3.412	0.001
Inglis & Lawson (1984)	0.009	0.080	0.006	-0.148	0.167	0.114	0.909
Ounsted, Cockburn, & Moar (1985)	0.056	0.211	0.045	-0.358	0.470	0.263	0.793
Witelson et al. (2006)	-0.268	0.203	0.041	-0.667	0.130	-1.319	0.187
Ghayas & Adil (2007)	0.410	0.165	0.027	0.087	0.734	2.485	0.013
Nicholls et al. (2010)	-0.053	0.127	0.016	-0.301	0.196	-0.415	0.678
Tomprou (2013)	0.131	0.341	0.116	-0.537	0.800	0.385	0.700
Koufaki (2014)	-0.366	0.438	0.192	-1.224	0.493	-0.835	0.404
	-0.071	0.023	0.001	-0.116	-0.026	-3.087	0.002

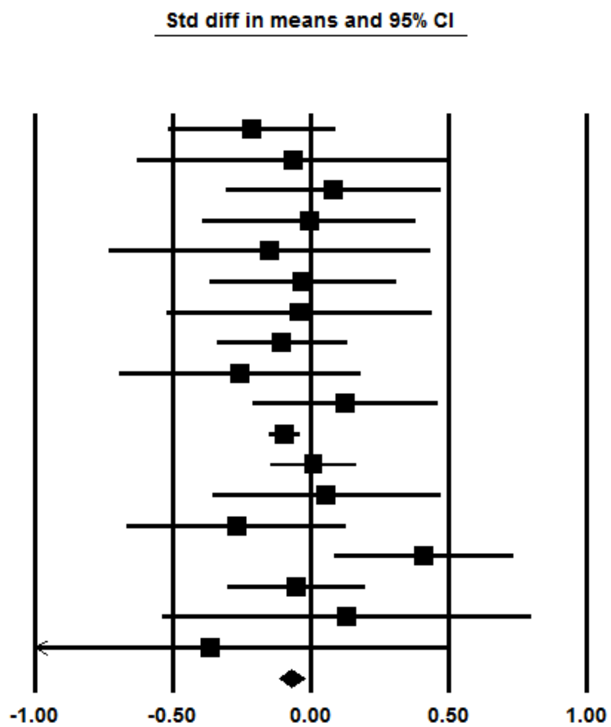

Figure 3 Forest plot of the standardized differences in mean IQ scores between right- and left-handers, presented separately for males and females. In the plot the 95% confidence interval for each study is represented by a horizontal line and the point estimate (Cohen's *d*) is represented by a square. The confidence intervals for the overall mean effect size are represented by a diamond shape at the bottom of the plot. Horizontal lines with arrows indicate that the confidence interval exceeds ±2 Cohen's *d*.

Study name	Subgroup within study	Statistics for each study						
		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Newcombe & Ratcliff (1973)	females	-0.026	0.306	0.094	-0.626	0.574	-0.085	0.932
Fagan-Dublin (1974)	females	0.148	0.487	0.237	-0.806	1.102	0.305	0.761
Newcombe et al. (1975)	females	-0.058	0.263	0.069	-0.573	0.458	-0.220	0.826
Sherman (1979)	females	-0.138	0.173	0.030	-0.478	0.202	-0.794	0.427
Mascie-Taylor (1980)	females	0.396	0.231	0.054	-0.058	0.849	1.710	0.087
McManus & Mascie-Taylor (1983)	females	-0.073	0.043	0.002	-0.157	0.012	-1.690	0.091
Inglis & Lawson (1984)	females	-0.107	0.119	0.014	-0.340	0.126	-0.898	0.369
Witelson et al. (2006)	females	-0.721	0.284	0.081	-1.278	-0.163	-2.535	0.011
Nicholls et al. (2010)	females	-0.100	0.187	0.035	-0.466	0.266	-0.536	0.592
Tomprou (2013)	females	-0.008	0.533	0.284	-1.053	1.038	-0.014	0.988
		-0.076	0.037	0.001	-0.149	-0.004	-2.075	0.038
Newcombe & Ratcliff (1973)	males	0.129	0.265	0.070	-0.389	0.648	0.489	0.625
Fagan-Dubin (1974)	males	-0.309	0.379	0.144	-1.052	0.434	-0.815	0.415
Newcombe et al. (1975)	males	-0.041	0.230	0.053	-0.491	0.410	-0.176	0.860
Sherman (1979)	males	-0.139	0.175	0.031	-0.482	0.204	-0.795	0.427
Mascie-Taylor (1980)	males	-0.167	0.255	0.065	-0.667	0.332	-0.657	0.511
McManus & Mascie-Taylor (1983)	males	-0.091	0.037	0.001	-0.164	-0.019	-2.480	0.013
Inglis & Lawson (1984)	males	0.091	0.109	0.012	-0.123	0.306	0.837	0.403
Witelson et al. (2006)	males	0.074	0.309	0.096	-0.532	0.680	0.240	0.810
Nicholls et al. (2010)	males	-0.029	0.172	0.030	-0.367	0.309	-0.168	0.867
Tomprou (2013)	males	0.172	0.444	0.197	-0.699	1.043	0.387	0.699
Koufaki (2014)	males	0.000	0.506	0.256	-0.991	0.991	0.000	1.000
		-0.070	0.032	0.001	-0.133	-0.007	-2.166	0.030
		-0.073	0.024	0.001	-0.120	-0.025	-2.997	0.003

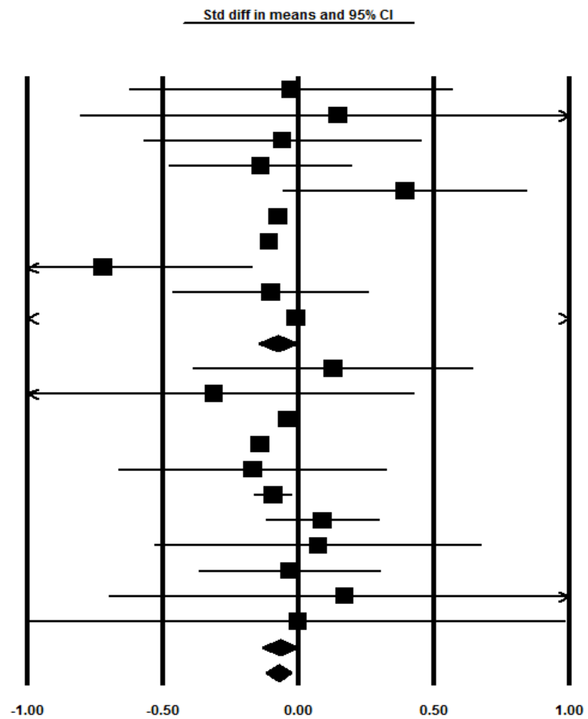

Figure 4 Funnel plot of standard error by standardized differences in mean IQ scores between right- and left-handers. White circles represent observed studies and black circles imputed studies.

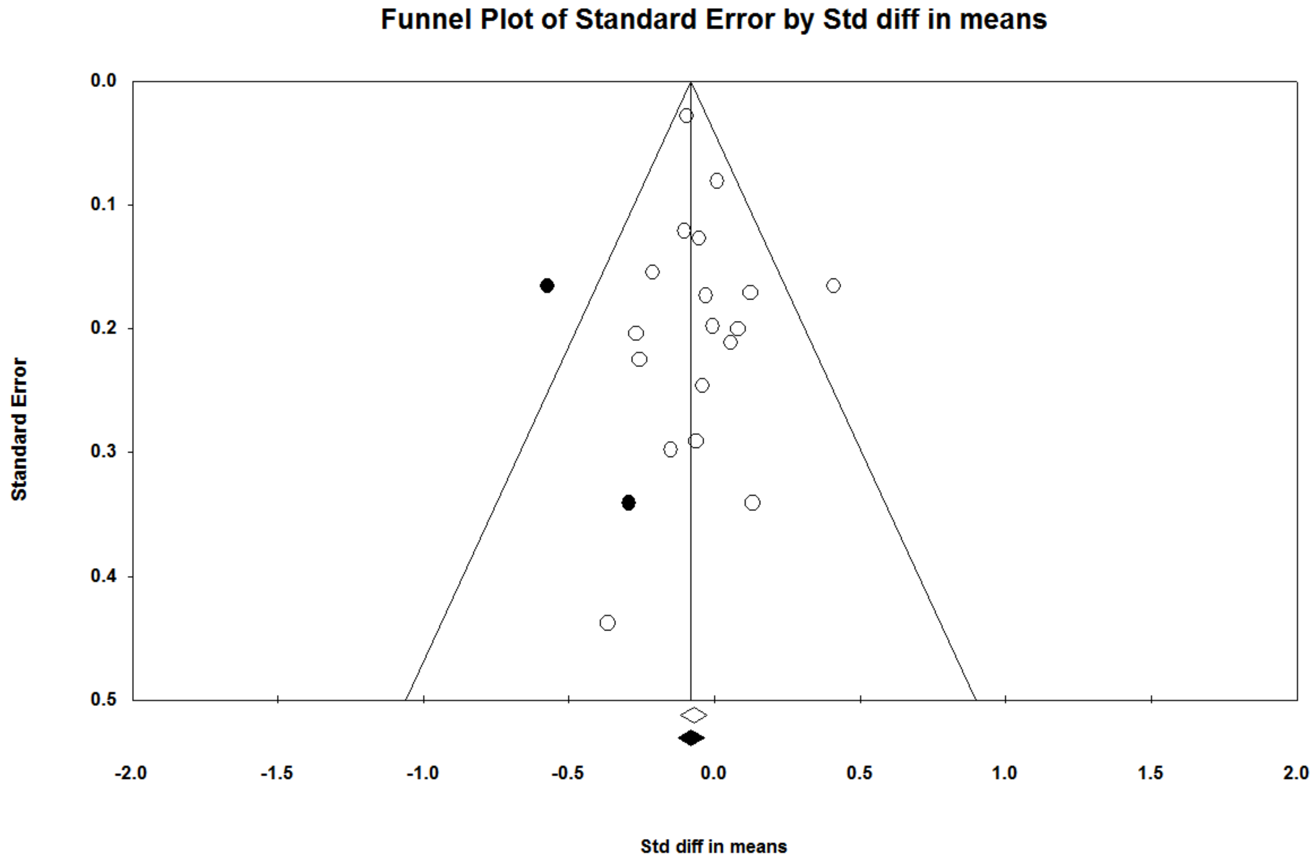

Figure 5 Forest plot of the standardized differences in mean IQ scores between right- and non-right-handers. In the plot the 95% confidence interval for each study is represented by a horizontal line and the point estimate (Cohen's *d*) is represented by a square. The confidence intervals for the overall mean effect size are represented by a diamond shape at the bottom of the plot.

Study name	Statistics for each study						
	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Wilson & Dolan (1931)	-0.213	0.154	0.024	-0.515	0.090	-1.379	0.168
Gibson (1973)	-0.062	0.291	0.085	-0.632	0.507	-0.215	0.830
Newcombe & Ratcliff (1973)	0.153	0.087	0.008	-0.018	0.324	1.758	0.079
Annett & Turner (1974)	-0.003	0.138	0.019	-0.274	0.268	-0.022	0.982
Fagan-Dubin (1974)	-0.150	0.298	0.089	-0.734	0.434	-0.503	0.615
Newcombe et al. (1975)	0.131	0.082	0.007	-0.029	0.290	1.601	0.109
Hicks & Beveridge (1978)	-0.041	0.246	0.060	-0.522	0.441	-0.165	0.869
Sherman (1979)	-0.104	0.121	0.015	-0.341	0.133	-0.859	0.390
Bishop (1980)	-0.256	0.225	0.050	-0.697	0.184	-1.141	0.254
Mascie-Taylor (1980)	-0.209	0.077	0.006	-0.358	-0.059	-2.725	0.006
McManus & Mascie-Taylor (1983)	-0.095	0.028	0.001	-0.150	-0.041	-3.412	0.001
Inglis & Lawson (1984)	0.009	0.080	0.006	-0.148	0.167	0.114	0.909
Ounsted, Cockburn, & Moar (1985)	0.056	0.211	0.045	-0.358	0.470	0.263	0.793
Witelson et al. (2006)	-0.268	0.203	0.041	-0.667	0.130	-1.319	0.187
Ghayas & Adil (2007)	0.410	0.165	0.027	0.087	0.734	2.485	0.013
Nicholls et al. (2010)	-0.053	0.127	0.016	-0.301	0.196	-0.416	0.678
Tomprou (2013)	0.131	0.341	0.116	-0.537	0.800	0.385	0.700
Koufaki (2014)	-0.366	0.438	0.192	-1.224	0.493	-0.835	0.404
	-0.031	0.039	0.002	-0.108	0.046	-0.783	0.434

Std diff in means and 95% CI

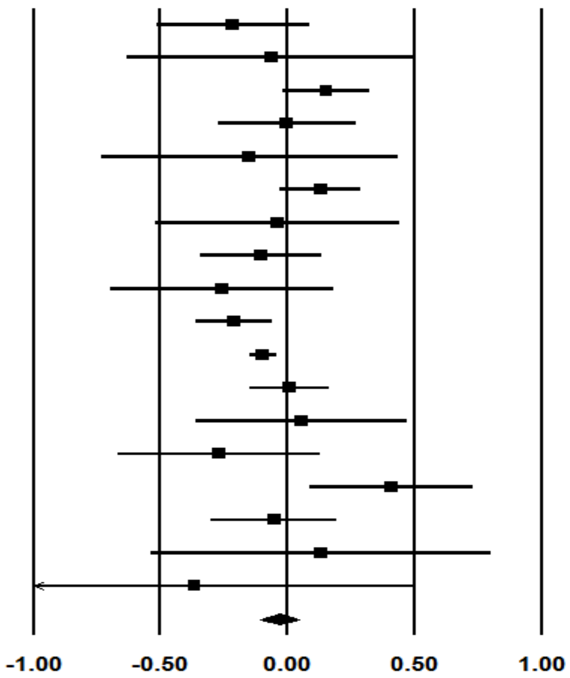

Figure 6 Forest plot of the standardized differences in mean IQ scores between right- and non-right-handers, presented separately for males and females. In the plot the 95% confidence interval for each study is represented by a horizontal line and the point estimate (Cohen's *d*) is represented by a square. The confidence intervals for the overall mean effect size are represented by a diamond shape at the bottom of the plot. Horizontal lines with arrows indicate that the confidence interval exceeds ±2 Cohen's *d*.

Study name	Subgroup within study	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Newcombe & Ratcliff (1973)	females	0.138	0.142	0.020	-0.140	0.416	0.974	0.330
Fagan-Dublin (1974)	females	0.148	0.487	0.237	-0.806	1.102	0.305	0.761
Newcombe et al. (1975)	females	0.112	0.131	0.017	-0.146	0.369	0.850	0.395
Sherman (1979)	females	-0.138	0.173	0.030	-0.478	0.202	-0.794	0.427
Mascie-Taylor (1980)	females	-0.082	0.108	0.012	-0.293	0.128	-0.765	0.444
McManus & Mascie-Taylor (1983)	females	-0.073	0.043	0.002	-0.157	0.012	-1.690	0.091
Inglis & Lawson (1984)	females	-0.107	0.119	0.014	-0.340	0.126	-0.898	0.369
Witelson et al. (2006)	females	-0.721	0.284	0.081	-1.278	-0.163	-2.535	0.011
Nicholls et al. (2010)	females	-0.100	0.187	0.035	-0.466	0.266	-0.536	0.592
Tomprou (2013)	females	-0.008	0.533	0.284	-1.053	1.038	-0.014	0.988
		-0.060	0.049	0.002	-0.155	0.036	-1.226	0.220
Newcombe & Ratcliff (1973)	males	0.118	0.113	0.013	-0.103	0.338	1.044	0.296
Fagan-Dubin (1974)	males	-0.309	0.379	0.144	-1.052	0.434	-0.815	0.415
Newcombe et al. (1975)	males	0.097	0.106	0.011	-0.111	0.304	0.915	0.360
Sherman (1979)	males	-0.139	0.175	0.031	-0.482	0.204	-0.795	0.427
Mascie-Taylor (1980)	males	-0.342	0.109	0.012	-0.556	-0.128	-3.130	0.002
McManus & Mascie-Taylor (1983)	males	-0.091	0.037	0.001	-0.164	-0.019	-2.480	0.013
Inglis & Lawson (1984)	males	0.091	0.109	0.012	-0.123	0.306	0.837	0.403
Witelson et al. (2006)	males	0.074	0.309	0.096	-0.532	0.680	0.240	0.810
Nicholls et al. (2010)	males	-0.029	0.172	0.030	-0.367	0.309	-0.168	0.867
Tomprou (2013)	males	0.172	0.444	0.197	-0.699	1.043	0.387	0.699
Koufaki (2014)	males	0.000	0.506	0.256	-0.991	0.991	0.000	1.000
		-0.046	0.046	0.002	-0.135	0.043	-1.008	0.314
		-0.052	0.033	0.001	-0.118	0.013	-1.574	0.116

Std diff in means and 95% CI

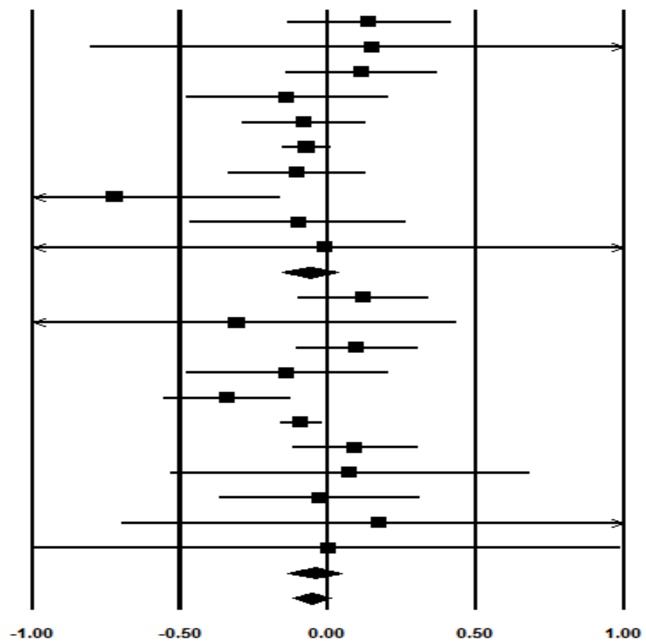

Figure 7 Funnel plot of standard error by standardized differences in mean IQ scores between right- and non-right-handers.

White circles represent observed studies and black circles imputed studies.

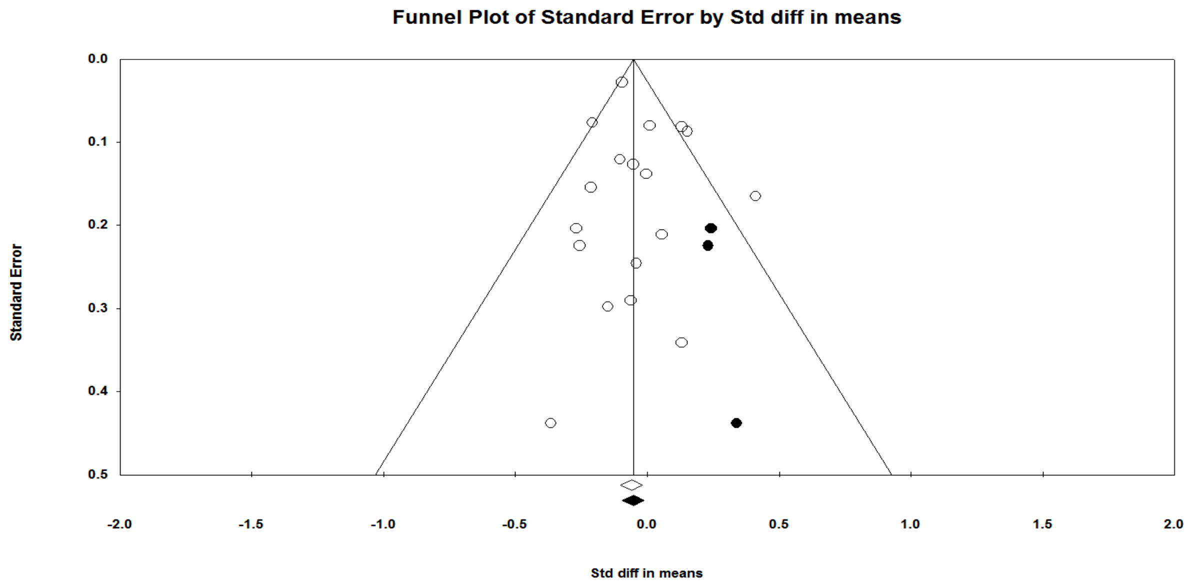

Figure 8 Forest plot of the standardized differences in mean IQ scores between right- and mixed-handers. In the plot the 95% confidence interval for each study is represented by a horizontal line and the point estimate (Cohen's *d*) is represented by a square. The confidence intervals for the overall mean effect size are represented by a diamond shape at the bottom of the plot. Horizontal lines with arrows indicate that the confidence interval exceeds ±2 Cohen's *d*.

Study name	Statistics for each study						
	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Newcombe & Ratcliff (1973)	0.165	0.093	0.009	-0.018	0.348	1.769	0.077
Annett & Turner (1974)	-0.002	0.147	0.022	-0.291	0.286	-0.014	0.989
Newcombe et al. (1975)	0.165	0.089	0.008	-0.008	0.339	1.865	0.062
Mascie-Taylor (1980)	-0.248	0.079	0.006	-0.402	-0.093	-3.134	0.002
	0.018	0.114	0.013	-0.206	0.243	0.162	0.872