The incidence of left-handedness: a meta-analysis

Beatrice M. Seddon and I.C. McManus (1993, unpublished)

This paper is probably the most cited of my unpublished manuscripts. It had a chequered publication history, some of which does not reflect well on a prestigious journal, and is probably better not described any further. For various and complex reasons it became difficult to revise the paper, and the manuscript then became somewhat dated, more studies having been published, and the was eventually left in the filing cabinet. However various people knew about it, and it has been cited on a number of occasions, most particularly by myself in the 1991 Ciba Symposium (McManus, 1991), where the two figures were also published in slightly modified form (and where 'incidence' in the title erroneously became 'inheritance').

The version presented here is based on a file on my computer dated 2nd January 1993, although there is also a somewhat modified form dated 11th October 1994. Some minor formatting has been carried out in converting a WordPerfect 5.1 file using an early version of Reference manager to a file in WordPerfect 9 with Reference Manager 9, including setting the references in APA 4 format[*]. No changes have been made to the text itself, with a single exception where a reference could not be found. The paper has been set in single spacing to help those who wish to print out the document.

I. C. McManus. The inheritance of left-handedness. In: *Biological asymmetry and handedness (Ciba foundation symposium 162)*, edited by G. R. Bock and J. Marsh, Chichester:Wiley, 1991, p. 251-281.

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[*] Despite the file being in WordPerfect 5.1, WordPerfect 9 would not read it, and the file had to be ported through Word 97. The effect on the equations in Appendix 1 was particularly dire. Appendices 1 and 2 have therefore been scanned in from a hard copy, and their page numbers are therefore somewhat out of sequence.

The incidence of left-handedness: a meta-analysis.

Beatrice M. Seddon[1]

I.C. McManus[1,2]

[1] Department of Psychology

University College London

Gower Street

London WC1E 6BT

[2] Department of Psychiatry

St. Mary's Hospital Medical School

Praed Street

London W2 1NY

Abstract.

A meta-analysis is reported of 88 studies, examining 100 study populations, in which the handedness of 284665 individuals has been assessed. The overall incidence of left-handedness was 7.78%. The incidence of left-handedness was not related to the method of measurement, or the length or number of response items included in inventories. Study populations with lower response rates and smaller study populations showed some evidence of higher incidences of left-handedness, presumably due to response biasses. There was no evidence that the incidence of left-handedness was related to the year of publication of studies; however the incidence of left-handedness was lower in older subjects and in those from earlier birth cohorts, the two effects not being statistically distinguishable.

Information was available from 64 study populations concerning the incidence of left-handedness in males and females; overall 8.52% of males were left-handed compared with 6.69% of females, the male incidence being 27.4% higher than that in females. Although there was some suggestion that the sex difference was greater in larger studies, and in studies whose main purpose was not the study of handedness, these differences were not significant. It is concluded that the size of the sex difference is unrelated to any of the moderator variables we have studied.

It was not possible to carry out a meta-analysis of degree of handedness due to wide-spread differences in the method of reporting of degree of handedness.

We recommend that future studies of handedness should, as a minimum, use one of three standard methods of assessment, so that comparison of studies is facilitated.

The majority of humans use their right hand for writing and for carrying out complex manipulative tasks. Humans therefore differ significantly from other mammalian species in which handedness or pawedness has been systematically measured in that although *individuals* are typically right- or left-handed (or pawed), at the *population* level approximately 50% of individuals are right-handed and 50% are left-handed. Considering studies in which hand or paw preference has been measured directly (and ignoring indirect evidence of behavioural asymmetries (Bradshaw, J. L., 1991), such as in the impala (Jarman, P. J., 1972), or anecdotal reports, as for the left-handedness of polar bears (Lopez, B., 1986)), there is no evidence for population-level handedness in mice (Collins, R. L., 1985), rats (Kirk, S. A., 1935; Uguru-Okorie, D. C. & Arbuthnott, G. W., 1981), cats (Burgess, J. W. & Villablanca, J. R., 1986; Cole, J., 1955), and probably monkeys (Brooker, R. J., Lehmann, R. A. W., Heimbuch, R. C., & Kidd, K. K., 1981) and apes (Byrne, R. W. & Byrne, J. M., 1991; Annett, M. & Annett, J., 1991), although the latter cases are controversial (MacNeilage, P. F., Studdert-Kennedy, M. G., & Lindblom, B., 1987; Marchant, L. F. & McGrew, W. C., 1991; McGrew, W. C. & Marchant, L. F., 1992). In non-mammalian species, the parrot may be an unusual exception to the above rule (Harris, L. J., 1989).

Right-handedness is an ancient human characteristic, being recognisable for at least 5000 years in works of art (Coren, S. & Porac, C., 1977c), where it shows a stable incidence of about 7.4%; other artefacts, such as bone and antler implements from the Neolithic period, about 7000 years ago, also show evidence of a predominance of right-handedness (Spenneman, D. R., 1984), as do Upper Palaeolithic scrapers from 8 to 35,000 years ago(Semenov, S. A., 1964), and stone tool flakes from 150-200,000 years ago (Cornford, J. M., 1986). Although the evolution of the genus *Homo* is complex (Wood, B., 1992a; Andrews, P., 1992), it does seem that recognisable human remains can first be found in the fossil record some 2.4 Million years ago (Hill, A., Ward, S., Deino, A., Curtis, G., & Drake, R., 1992; Wood, B., 1992b), at a similar time to that at which the first stone tools are also discovered. The stone tools produced in the lower Pleistocene (Toth, N., 1985; Lewin, R., 1986), as well as the patterns of wear on teeth (de Castro, J. M. B., Bromage, T. G., & Jalvo, Y. F., 1988; Bahn, P. G., 1989), are both characteristic of those produced by right-handed individuals, suggesting that tool usage was associated with a population level right-handedness. The implication is that the evolution of tool usage and right-handedness may have been causally linked, at a point when man and the apes were diverging.

Functional cerebral lateralisation, with linguistic functions being generally being located in the left hemisphere (Bryden, M. P., 1982), was first clearly recognised by Broca, who, in 1863, described over 25 patients, all of whom suffered from what we would now call aphasia, or lack of speech, and all of whom had suffered from lesions to the left side of the brain (Berker, E. A., Berker, A. H., & Smith, A., 1986; Broca, P., 1865) (although he had undoubtedly been anticipated by Wigan and Dax - for more detailed historical accounts see (Harrington, A., 1987; Hécaen, H. & Lanteri-Laura, G., 1977) and (Hécaen, H. & Dubois, J., 1969)). Since that time it has become apparent that cerebral lateralisation for language is related to handedness, left-handers more often showing non-left sided cerebral dominance for language (Damasio, A. R., 1992; Woods, R. P., Dodrill, C. B., & Ojemann, G. A., 1988; Benson, D. F., 1986). Additionally left-handers do not show the typical pattern of anatomical asymmetries in the planum temporale (Geschwind, N. & Levitsky, W., 1968), instead showing a greater degree of symmetry (Steinmetz, H., Volkmann, J., Jaencke, L., & Freund, H-J., 1991).

There is some suggestion that left-handedness may sometimes be the result of cultural (Dawson, J. L. M. B., 1972; Harris, L. J., 1990; Provins, K. A., 1990), learned (Michel, G. F. & Harkins, D. A., 1985), environmental (Porac, C., Coren, S., & Searleman, A., 1986c; Porac, C., Izaak, M., & Rees, L., 1990) or pathological factors

(Harris, L. J. & Carlson, D. F., 1988; Soper, H. V. & Satz, P., 1984; McManus, I. C., 1983a), although the evidence in each case is weak, and not supported by evidence of similar incidences of handedness between very different cultures (Connolly, K. & Bishop, D. V. M., 1992), the statistical lack of power of studies in small remote cultures to distinguish environmental from genetic factors (McManus, I. C. & Bryden, M. P., 1993a), by the relative unimportance of intra-familial learning processes (Leiber, L. & Axelrod, S., 1981a), by the almost minimal effects of birth stress upon the incidence of handedness (Searleman, A., Porac, C., & Coren, S., 1989), and by only 5% or so of left-handers showing evidence compatible with pathological origins (Bishop, D. V. M., 1990). There is however clear evidence that left-handedness runs in families (McManus, I. C. & Bryden, M. P., 1992), and is associated with the handedness of biological rather than adoptive parents (Carter-Saltzmann, L., 1981), implying, at least in part, a genetic origin for the trait. Although many genetic models have been proposed, which have been reviewed elsewhere (McManus, I. C. & Bryden, M. P., 1992), there are at present only two potentially adequate models which can explain data from families, twins, and sex differences, the models of Annett (Annett, M., 1985), and McManus (McManus, I. C., 1985a; McManus, I. C., 1991; McManus, I. C. & Bryden, M. P., 1992). The models are similar in postulating one allele that produces 'fluctuating asymmetry' (Palmer, A. R. & Strobeck, C., 1986), a condition in which 50% of the population are right-handed and 50% are left-handed (i.e. the situation found in most non-human species), with another allele that produces a directional asymmetry in which the majority of the individuals are right-handed. The models differ in other important respects (McManus, I. C., 1985b; McManus, I. C., 1985c; McManus, I. C., Shergill, S., & Bryden, M. P., 1993), most notably in their emphasis upon the primary dimension being preference or skill asymmetries, the Annett model emphasising the primary role of skill differences, whereas the McManus model emphasises the importance of preference (McManus, I. C., 1991). Although the primacy of preference over skill is difficult to assess (Morgan, M. J. & McManus, I. C., 1988), the presence of preference asymmetry in the absence of skill asymmetry in children with autism does suggest that preference is primary (McManus, I. C., Murray, B., Doyle, K., & Baron-Cohen, S., 1992).

Considering the broad pattern of evidence on right-handedness it is possible to make a case for a strong hypothesis which suggests that right-handedness, along with the capacity to make and use tools, to use language, and to show functional and anatomical cerebral specialisation, are characteristics which together are characteristic of humans, and that they are intimately tied together in the divergent evolution of man from the apes (Frost, G. T., 1980; Calvin, W. H., 1982; Varney, N. R. & Vilensky, J. A., 1980). This divergence occurred about two and a half million years ago, perhaps as the result of a genetic mutation whereby a gene that once influenced the asymmetry of the viscera instead caused the asymmetric development of the brain, resulting in handedness and language dominance (McManus, I. C., 1991). If this hypothesis is correct then the understanding of right-handedness (and by implication, left-handedness also) is of the greatest importance for understanding the origins of humans, and for understanding the relationships between handedness and language lateralisation, and their neurobiological instantiation. Language lateralisation is intrinsically difficult to study (and even the best techniques, such as dichotic listening have relatively poor reliability and validity (Bryden, M. P., 1988a; Bryden, M. P., 1988b)). In contrast since handedness is potentially straightforward to assess in large numbers of individuals, using questionnaires or inventories, handedness represents a convenient surrogate for studying the wider aspects of cerebral lateralisation which particularly interest psychologists. A case can therefore be made that finding the gene for handedness will be the key that unlocks the neurobiology of language (McManus, I. C., 1991), and that the molecular genetics of cerebral lateralisation is a feasible objective for neuroscience (McManus, I. C. & Bryden, M. P., 1993b). However adequate genetics requires an adequate phenotypics (McManus, I. C. & Bryden, M. P., 1992), and unless the phenotypes of right- and left-handedness are well characterised then the genetics of handedness is likely to be flawed. The present meta-analytic study therefore reviews a large number of studies which have measured the incidence of left-handedness in different populations, using different measuring instruments in different ways, to determine how the methods of study and the characteristics of the subjects relate to the incidence of handedness that is found.

The incidence of left-handedness: why does it matter?.

In the majority of the population the right hand is more skilful and is preferred for use in manipulative tasks. The incidence of left-handedness has been measured in many studies, and is typically quoted as "about 10%", often with a comment to the effect that there seems to be much variation between populations (e.g. (Salmaso, D. & Longoni, A. M., 1985)), or that the method of classification is arbitrary, due to the phenomenon being distributed along a continuum (Maehara, K. et al., 1988). If a process is genetic then it is important to know whether there is significant variation between populations, either in space or in time. The absence of such variation implies the existence of a balanced polymorphism with strong selective pressures to maintain the two alleles in the gene-pool; the constraints upon a balanced polymorphism for handedness are discussed elsewhere (McManus, I. C., Shergill, S., & Bryden, M. P., 1993). By contrast, variation between populations may imply the existence of genetic drift, perhaps compounded with selective migration (Cavalli-Sforza, L. L. & Bodmer, W. F., 1971), as seems to be the case with hand-clasping and arm-folding, both of which show strong evidence of a cline across Europe and Asia (McManus, I. C. & Mascie-Taylor, C. G. N., 1979). Previous studies have suggested that the incidence of left-handedness has increased during the present century (Brackenridge, C. J., 1981; Levy, J., 1976). Similarly most genetic studies of handedness have found increased incidences of sinistrality in offspring as compared with parental generations (Ashton, G. C., 1982b; McManus, I. C., 1985a), although some of this difference between generations almost certainly reflects reporting biasses due to offspring inaccurately describing the handedness of their parents and grandparents (Porac, C. & Coren, S., 1979). Over a far longer time-scale, and in contrast to these apparent short-term effects during this century and between generations, the study of hand usage in works of art (Coren, S. & Porac, C., 1980) found an incidence of about 7.4% which was unchanged over the past five millennia.

The relationship between handedness and the age of subjects, has become of importance as a result of the hypothesis of Halpern and Coren that left-handers die at an earlier age than right-handers (Halpern, D. F. & Coren, S., 1988b; Coren, S. & Halpern, D. F., 1991; Halpern, D. F. & Coren, S., 1990b), and have a greater number of accidents (Coren, S., 1989). The hypothesis is controversial (Harris, L. J., 1993; Pool, R., 1991), and there have been criticisms of methodology (Charles, D., 1991; Harris, L. J., 1993; Anderson, M. G., 1989b; Rothman, K. J., 1991), and failures to replicate empirical claims (Marks, J. S. & Williamson, D. F., 1991; Wolf, P. A., D'Agostino, R. B., & Cobb, J., 1991; Peters, M. & Perry, R., 1992). Nevertheless there does seem to be general agreement that the incidence of handedness seems to decrease with age and to have increased in recent years (Strang, J., 1991; Dellatolas, G. et al., 1991; Fleminger, J. J., Dalton, E., & Standage, K. F., 1977; Porac, C., Izaak, M., & Rees, L., 1990; Brackenridge, C. J., 1981; Levy, J., 1974; Beukelaar, L. J. & Kroonenberg, P. M., 1986), and that therefore some of the effects reported by Halpern and Coren may represent secular trends, reflected in cohort effects, rather than effects of differential mortality. In the present study we attempt to disconfound three variables that are potentially confounded: the age of subjects; the year of birth of subjects; and the year in which a study is carried out.

Variation in apparent incidence between populations may also reflect less substantive processes such as different methods of measurement or of different criteria for defining sinistrality. Response biasses on the part of respondents, due to social or other pressures, or due to volunteering behaviour (Rosenthal, R. & Rosnow, R. L., 1975) may also produce biassed estimates of the incidence of left-handedness, reflecting the complex social dynamics of participation in psychological experiments (Orne, M. T., 1962). To take an example, the commonly quoted excess of left-handedness in males (Oldfield, R. C., 1971; Levy, J., 1976) may reflect a tendency of left-handed males to be more likely to respond to questionnaires. Evidence presented elsewhere has suggested that left-handers respond more quickly to a questionnaire which is principally concerned with handedness, and that they have a higher overall response rate, thereby providing potential biasses in assessment of rates (Cornell, E. & McManus, I. C., 1992). Similarly van Eys and McKeever (, 1988a) have shown that subjects' knowledge of an experimenter's interest in lateralisation can modify the results of a dichotic listening task.

In this paper we provide a meta-analysis of a number of studies which have assessed the incidence of left-handedness in populations which were intended to be representative of the general population. In particular we consider the overall population incidence in relation to time and place of measurement, we examine the question of sex differences, and we look at the effects of possible measurement artefacts upon rates in the form of length and type of questionnaires, method of administration, and the nature of the study.

Method

The literature on lateralisation is large. McManus (, 1986a) estimated that about 5000 papers had been published by 1985; updating that survey suggests that between 1960 and 1989, 6564 papers were cited in *Psychological Abstracts* under the headings of Cerebral Dominance, Handedness and Lateral Dominance, with 1047 being cited under the heading of Handedness alone. This meta-analysis could not, therefore, hope to provide a complete review of all studies of laterality, and instead we used a sampling strategy that was intended to provide a representative sample of published papers. The complete runs of several journals for the years 1960 to 1989 were assessed and all papers on handedness within that period were included, as also were all papers referred to secondarily by those papers. Additionally we included all papers on handedness which were included in the reprint collection of one of us (ICM), and we also included the as yet unpublished data from three large population-based studies in which ICM has been involved. This sampling strategy produced a relative dearth of studies published earlier in the century, and therefore we also made a conscious effort to find any papers with estimates of handedness incidences which were published prior to 1960.

The journals *Cortex* (1964-1989) and *Neuropsychologia* (1963-1989) were chosen as representative of the neuropsychological literature, *Behaviour Genetics* (1977-1988) was chosen to reflect the genetic literature, *Human Biology* (1960-1989) to be representative of anthropology, and the *British Journal of Psychology* (1965-1989) was chosen as an example of a general interest journal. Papers were chosen for inclusion in the study if they met the following criteria:

i. The study as a whole assessed handedness in at least 100 individuals who were not selected specifically because of their pattern of lateralisation, and also were not some special subset of the general population (such as dyslexics, myasthenics, mathematicians or homosexuals, or those reported as having suffered from 'birth stress', etc.). The randomly selected control groups for specific population subsets were however included in the study. The total population data were also included from studies in which a complete population had been sub-divided for some specific purpose (such as comparing those reporting a history of birth stress with those not reporting such a history).

ii. The study specifically was investigating hand *preference* and was not only assessing differences in *skilled* hand performance. Studies were however included if hand preference was assessed directly by asking subjects to perform an unskilled task with one hand or the other, the principal measure being of the hand *preference* for the task.

iii. In general twin studies were excluded from the analysis, since a previous meta-analysis has suggested that different criteria have been applied in assessing the handedness of twins to assessing the handedness of singletons (McManus, I. C., 1980). We did decide to include any twin study in which singleton controls were assessed by identical criteria to those of the twins; in the event, no studies met this criterion.

iv. A number of studies presented their data only in terms of the classification described by Annett (Annett, M., 1967), in which subjects are divided into three handedness groups, left, right and mixed, with the latter category being very broadly defined as all individuals who are not consistently right-handed or consistently left-handed. That criterion results in a far lower incidence of 'left'-handedness and a very much higher incidence of 'mixed-handedness' than in other studies (typically of the order of 2-4% and 25-35%). We could find no straightforward way of including this classification within our analysis, and therefore if studies *only* reported their data in terms of this classification, and did not give sufficient information for us to re-code it in terms of a more conventional criterion, then we excluded it from the analysis.

v. Children were not included in the analysis unless they were at least seven years old (by which time most studies have suggested that the direction of handedness is well established (Hardyck, C., Goldman, R., & Petrinovich, L., 1975a; McManus, I. C. et al., 1988c)). The only exception concerned studies in which data were aggregated across a range of ages (such as "6-12") and in which the vast majority of children were aged over seven (e.g. the studies of Clark (Clark, M. M., 1957)).

Reasons for rejection of studies.
Studies were rejected for a range of reasons, only a brief summary of which will be given here. Many studies were excluded as their sample size was too small or because the sample was itself pre-selected on the basis of laterality (e.g. (Liederman, J. & Healey, J. M., 1986; Tan, L. E., 1983)). Other studies assessed the handedness only of a specialised group such as musicians (Oldfield, R. C., 1969; Byrne, B., 1974), without the inclusion of a control group. A number of studies reported data only in terms of the comparison of skilled performance of right and left hands, without giving preference data *per se* (e.g. (Heinlein, A., 1929; Durost, W. N., 1935; Bishop, D. V. M., 1986)). Some twin studies were excluded because of the absence of a singleton control group (e.g. (Shimizu, A. & Endo, M., 1983; Neale, M. C., 1988)). Some studies were rejected due to the subjects being less than seven years (Roos, M. M., 1935; Means, L. W. & Walters, R. E., 1982; Badian, N. A., 1983)). In some studies although it was apparent that relatively large amounts of data had been collected, these were not unfortunately in a form in which useful information could be extracted; examples include that of Downey (, 1927), in which an eccentric classification scheme was used. In some cases it was apparent that although several separate papers had been published, sometimes by different sets of authors, the studies were nevertheless re-analyses of a single, often very large, data set; examples include the studies of Nachson & Denno (, 1986b; Nachson, I. & Denno, D., 1987), which were excluded in favour of the more comprehensive account of the Philadelphia Collaborative Perinatal Project (Nachson, I., Denno, D., & Aurand, S., 1983); the study of Sanders *et al* (, 1982a) which was excluded in favour of the study of Ashton (, 1982b) of the Hawaii Family Study of Cognition; the study of Teng *et al* (, 1976a), excluded in favour of their later analysis of data in Teng *et al* (, 1979a); the study of Hardyck *et al* (, 1975a), excluded in favour of that of Hardyck *et al* (, 1976b); and the study of Leiber and Axelrod (, 1981a) excluded in favour of the more comprehensive study of Leiber and Axelrod (, 1981b).

Sampling frame. As far as was possible from the information given in each of the published studies, the method of recruitment of subjects and the possible bias in their collection was classified as follows. Particular in the case of the assessment of bias it was accepted that there was necessarily a subjective estimate in the assessment, although the two authors usually found themselves in agreement over classification.

Recruitment:

> *Group 1:* Self-selected volunteers, who were responding as a result of their own choice (e.g. Salmaso & Longoni (, 1983a);
> *Group 2:* A 'captive' population, representing a complete sample group, such as a whole school, (e.g. Rife (, 1940));
> *Group 3:* A proper random population sample (e.g. Karpinos (, 1953));
> *Group 4:* Indirect measurement of handedness. In some studies, particularly those interested in familial transmission of handedness, incidences of left-handedness are reported by individuals in their relatives. This group was classified separately since the subjects themselves have never actually been contacted directly by the experimenter.

Possible bias: A subjective assessment of the overall likelihood of bias in the selection of subjects was made by BMS, based on the information given in the paper. Four categories of bias were coded:

> *Group 1:* None; i.e. a completely random sample (e.g. Karpinos (, 1953));
> *Group 2:* Slight (e.g. Beckman *et al* (, 1962a));
> *Group 3:* Possible (e.g. Britto *et al* (, 1989a));
> *Group 4:* Probable (e.g. Birkett (, 1981c)).

Response rate was recorded as a percentage. In those many cases in which it was not available no attempt was made to estimate it, since a pilot study showed that no reasonable estimates could be made in most cases.
Main purpose of study. The main purpose of each study was classified into four groups, according to the range of information being collected, and the extent to which this was principally concerned with handedness or lateralisation. In cases of doubt the data collection process was viewed from the subject's point of view, to assess the extent to which subjects might perceive the study as being principally concerned with handedness rather than with a range of measures. The four categories were:

> *Group 1:* Handedness was the only principal measure (although possible causal influences upon handedness (such as birth stress) may also have been measured (e.g Jones and Bell (, 1980a)).
> *Group 2:* Handedness was one of a number of laterality measures collected; otherwise the study was classified as in the previous category; e.g. Searleman, Tweedy and Springer (, 1979b).
> *Group 3:* One or several other variables were the main rationale for the study, and handedness information was collected as a secondary purpose of the study (e.g. Heim and Watts (, 1976c)).
> *Group 4:* The study was a large, multivariate study in which many other variables were being measured, and handedness represented a tiny portion of the total data set. An example is the data collected by Newcombe *et al* (, 1973a).

Data re-classification. In considering a number of studies it was necessary or useful to re-classify or further process the data from the precise form presented by the original authors, in order to allow maximum comparability between studies. This process took three broad forms:

i. Extraction of data from graphs. In several studies (Provins, K. A., Milner, A. D., & Kerr, P., 1982c; Silverberg, R., Obler, L. K., & Gordon, H. W., 1979) a frequency distribution of laterality coefficients was presented and we used that information to calculate the proportion of subjects who had laterality coefficients less than or equal to zero, that precise information not being presented in the original text.

ii. Combination of categories from the original study. Some authors presented tabular data in a more detailed form than was required for this study, and by amalgamating several categories (e.g. weak and strong right-handers (Lansky, L. M., Feinstein, H., & Peterson, J. M., 1988)) we could reduce the data to a form compatible with other studies. In a few other cases (e.g. (Newcombe, F. G. et al., 1975)) the data were presented in a unique and idiosyncratic form, and required a complete re-classification which necessarily involved some minor arbitrary decisions.

iii. Combining sub-populations. Sometimes it was convenient to combine results from a number of sub-populations which were described separately in the original studies, as for instance in combining psychology and engineering students (Jones, B. & Bell, J., 1980a), or of individuals in different geographical areas (Ardila, A. et al., 1989).

Statistical analysis.

The statistical analysis of meta-analytic studies is not entirely uncontroversial; the problems have been reviewed recently (Hunter, J. E. & Schmidt, F. L., 1990a). A problem with any meta-analysis involving a quarter of a million subjects is that its results may only be significant in a statistical rather than a substantive sense. In this paper we have not depended solely upon formal statistical testing, and instead have also examined the overall patterns of results for relationships that appear theoretically meaningful and appear to be substantial in the sense that effect sizes are large enough to merit concern and interest. However we have however also carried out statistical testing of effects, to determine whether apparent effects of moderator variables is within the bounds of sampling variation. In so doing we are aware of the problem emphasised by Hunter and Schmidt (, 1990a) (p.86) that in examining meta-analytic data for effects of moderator variables then the crucial characteristic is the number of *studies* (100 in this case) and not the number of *subjects* (over a quarter of a million). Paradoxically this can mean that the power of meta-analytic studies is surprisingly low, despite their huge subject numbers. In using univariate and multivariate analysis of studies we have followed Glass (, 1977a) in not attempting to take any account of the differing sample sizes in studies (and hence their different sampling errors, and therefore their variance heterogeneity), since, despite the concerns of Hedges and Olkin (, 1985a), we have accepted the argument of Hunter and Schmidt (, 1990a) (p.408) that such problems pale into insignificance in comparison with the problems posed by low power in such studies. In assessing the effects of moderator variables we have therefore used unweighted population estimates from individual studies (i.e. irrespective of study sample size) and compared them by univariate analysis of variance and by multiple regression. In order that the reader can assess whether this may have seriously distorted the results we have presented descriptive statistics which are both weighted and unweighted means across studies.

Results.

Altogether 88 studies were included in the analysis, which analysed handedness in 100 separate populations, and considered a total of 284665 subjects. Details of the individual studies are shown in table 1. 48 (55%) studies were found by a systematic search through the back runs of journals, 30 (34%) were secondary references, cited in those studies, 10 (12%) were additional studies found in the reprint collection of one of the authors (ICM) or were unpublished studies, brief details of which are given in table 1. Some studies (Ramaley, F., 1913; Dawson, J. L. M. B., 1972) included several sets of data that could be regarded as studies of different populations (e.g. because they looked at several distinct age-groups, at different geographical areas, etc.). Not all information was always available for every study, for a variety of reasons.

Of the 88 studies, 5 were published before 1940, 2 in 1940-49, 5 in 1950-59, 4 in 1960-69, 21 in 1970-79, and 48 in 1980-89; an additional three studies were unpublished. The commonest sources of publications were *Cortex* (24), *Neuropsychologia* (19), *Human Biology* (8), *Behaviour Genetics* (4), *British Journal of Psychology* (3), and *Perceptual and Motor Skills* (3), with the remaining published studies coming from 17 different journals and 3 books.

Measurement of handedness.

In 52 studies (60%) handedness was assessed by some form of written questionnaire, and in 3 studies (3%) a questionnaire was administered verbally. 11 (13%) studies simply asked the subject whether they were right or left handed, and 13 (15%) studies asked the subjects which hand they used for writing. 7 (8.0%) studies assessed handedness by observing the subjects' preference for carrying out an unskilled task. In 2 (2%) studies the method of assessment was not clearly specified. 40 (45%) studies used a specific inventory, which was modified to some extent in 18 (42%) cases. The most popular inventory was the Edinburgh Handedness Inventory (Oldfield, R. C., 1971), being used in 14 studies; 5 studies used the inventory of Raczkowski *et al* (, 1974), 4 used the Crovitz and Zener (, 1962b) inventory, 4 used the Briggs and Nebes (, 1975b) inventory, 4 used the inventory of Porac and Coren (Porac, C. & Coren, S., 1981d), 3 used the Annett (, 1970) inventory, 2 the inventory of Provins *et al* (, 1982c), 2 the inventory of Bryden (, 1977b), and one each used the inventories of Hatta and Nakatsuka (, 1976d) and Hull (, 1936). Some other studies used their own specific inventories.

Amongst the inventories used, the mean number of questions was 15.3 (median 10.5, mode 10, SD 16.77, range 3 to 82). The individual items on inventories most commonly had 5 response categories (27; 55% of cases), with 3 items being the next most popular (16 cases; 33%), with 2 items (4 cases; 8%) and 6 or 7 items (1 case each, 2%) being much less popular.

The final classification of handedness was into Right and Left-handedness in 72 (82%) studies, into Right and Non-right-handedness in 3 studies (3%), and into Right, Mixed and Left-handedness in 13 (15%) cases. The classification into categories was based on a laterality coefficient or laterality quotient in most cases in which an inventory was used (in almost all cases using some transform of the formula (R-L)/(R+M+L)). In the 73 studies in which the criterion could be evaluated, 45 (62%) defined left-handedness as a laterality coefficient or equivalent of less than zero, 19 simply used the writing hand, and 9 used a criterion in which rights-handedness was defined as all inventory items being carried out with the right hand. 15 (17%) studies mentioned the possibility that some apparently right-handed subjects might be left-handers who had been forced to write with the right hand, and 4 (5%) studies (e.g. Shimizu and Endo, 1983) explicitly modified their incidence of left-handedness to take this into account.

The incidence of left-handedness.

The incidence of left-handedness will necessarily vary according to the nature of the categories used for describing it, and the criterion applied to it. Table 2 summarises the overall incidence of left-handedness according to whether the study populations distinguished right and left-handedness (R-L), right and non-right-handedness (R-NR) or right, mixed and left-handedness (R-M-L), and in the latter case according to whether non-right handedness was defined as left-handers only (i.e. L/(R+M+L)) or left- and mixed handers combined (i.e. (L+M)/(R+M+L)). The median and mean rates of non-right-handedness are calculated across *study populations*, whereas the overall rate of non-righthandedness is calculated across *subjects* in the study populations, each subject contributing equally to the final figure; it is therefore weighted so that larger studies contribute more to the estimate than do smaller studies. The overall incidence is probably the best single estimate of the population incidence of left-handedness. Figure 1 shows the incidence of left-handedness in each of the 100 study populations in relation to the specific criterion used for defining left-handedness.

From table 1 it is apparent that the commonest method of assessment, L/(R+L), gives a weighted mean population incidence of 7.68%. Interestingly using a criterion of L/(R+M+L), in which mixed handers or ambidexters are included as a possible response category, gives a very similar weighted mean incidence (8.06%), in comparison with the more liberal criterion of (L+M)/(R+M+L) which gives a much higher incidence of 15.16%. The rarely used criterion of R/(R+NR) gives a somewhat higher weighted mean incidence, of 11.38%, although there are only 3 study populations with that criterion. In order to simplify further analyses in this paper we have combined three criteria, and have excluded the fourth criterion of (L+M)/(R+M+L), to give the data shown in the final row of figure 1. This gives a final overall incidence of 7.78% for the entire population, based on 284665 subjects.

Method of measurement and subjects. Table 3 shows that whether handedness is assessed by questionnaire, performance or a simple question (such as about writing hand or the handedness of the subject) has almost no effect upon the overall incidence of sinistrality ($F(4,93)=.726$, NS). In studies using a formal questionnaire or inventory, table 4 shows that there is neither an overall relationship ($F(4,47)=.122$, NS) nor a linear relationship ($F(1,47)=.141$, NS) between the number of items and the incidence of left-handedness, and table 5 shows that there is no evidence of a relationship between the number of response categories for each item and the overall incidence of sinistrality (Overall: $F(2,46)=.422$, NS; Linear $F(1,46)=.261$, NS).

In the 100 study populations, 26 (26%) used self-selected volunteers, 28 (28%) used a captive whole group of some sort, 39 (39%%) used a proper random sample and 7 (7%) consisted of left-handedness incidences reported indirectly in others from memory (e.g. parents or grandparents). The sampling method by which the subjects are obtained does seem to have some influence upon the overall incidence of left-handedness (table 6), with self-selected volunteers having a higher incidence of left-handedness than do more systematic methods of obtaining subjects, although the effect is not statistically significant ($F(3,96)=1.37$, NS); indirect reporting of others' handedness is associated with a lower rate of left-handedness, as might be expected from the results of Porac and Coren (, 1981d). Our subjective assessment of the possible extent of bias occurring during the selection of subjects also shows a clear relationship to the incidence of sinistrality, table 7 showing that biassed studies have a higher incidence of left-handedness than do unbiased studies (Overall $F(3,96)=1.63$; Linear $F(1,96)=3.698$, $p=.0574$). The response rate was known or estimated in 24 study populations, and had a mean of 79% (SD 27.7%; range 23 - 100%; median 95%). Table 8 summarises the relationship between response rate and the incidence of left-handedness; there is some suggestion that lower response rates are associated with higher incidences of left-handedness, as might be expected from the results described earlier of Cornell and McManus (, 1992), although the effect does not show statistical significance (Overall $F(3,27)=.725$; NS: Linear $F(1,27)=.510$, NS).

Characteristics of study populations. Study populations varied in size, having a mean of 2846 subjects (median = 964, SD = 7655, range = 95 - 72238, N=100). Table 9 shows that the incidence of left-handedness is lower in the larger study populations, with a particular difference between studies larger than 250 subjects and those less than 250 subjects; nevertheless the linear trend was not significant ($F(1,96)=2.01$, NS). There was also some slight difference in the incidence of left-handedness according to the source of the study; table 10 shows that the study populations obtained through a systematic random search through runs of journals had a slightly higher incidence of left-handedness than the studies obtained as references from those papers, or from a search through the file collection of ICM; the effect is just at the conventional level of statistical significance ($F(2,97)=3.08$, $p=.050$). In part this difference may be explicable by the different sample sizes used in the papers in the different categories, the systematic papers tending to have lower sample sizes (mean = 1658) than those which were obtained as secondary references (mean = 5200), although the personal collection papers had a similar mean size to those in the systematic search (mean= 1567).

The main purpose of studies varied, with the principal interest being handedness in 57 (57%) study populations, laterality in general in 20 (20%) studies, other variables in 10 (10%) studies, and being part of a large multivariate study in 13 (13%) study populations. Table 11 shows that the incidence of left handedness was lower in those study populations in which handedness was only one of many variables, as compared with those in which lateralisation was the principal purpose of the study, although the effect was not statistically significant ($F(3,84)=.247$, NS).

Cohort and age effects. Table 12 examines the relationship between the year in which a study population was investigated and the overall incidence of left-handedness; there is some sign that studies carried out later in the century show higher rates of left-handedness (Linear: $F(1,96)=5.94$, $p=.017$), although the effect is stronger for the unweighted means than for the (weighted) overall incidences. A similar pattern is seen in table 13 for the relationship between the estimated year of birth of subjects and the overall incidence of left-handedness, although the linear trend across the means is significant ($F(1,73)=6.52$, $p=.013$); examining the (weighted) overall incidences suggests only that the incidence appears lower in the few studies with subjects born before 1910. Table 14 assesses the overall incidence of handedness in relation to the estimated age of the subjects. There is little difference in incidence of left-handedness in subjects aged under 45, but above this age there does appear to be a diminished incidence of left-handedness. The overall difference between groups is not significant ($F(6,71)=1.486$, NS), although the linear trend is significant ($F(1,71)=6.20$, $p=.015$), without a significant non-linear trend ($F(5,71)=.542$, NS).

Geographical region. Table 15 summarises the incidence of left-handedness according to the geographical area in which the data were collected. There seems to be little evidence for large differences in incidence according to the geographical area of origin ($F(5,94)=.701$, NS).

Multivariate analysis of overall incidences. The univariate analyses described above have suggested that several of the moderator variables in tables 3 to 15 have effects upon the overall incidence of left-handedness. In order to assess these effects more clearly we have used a multiple regression analysis in which the dependent variable was the overall incidence of left-handedness in a study, and the independent variables consisted of all those moderator variables in which univariate analyses suggested the possibility of significant effects at least at the 0.2 level (either overall or for the linear trend as appropriate). This resulted in six variables being entered into the analysis which was carried out by a forward stepwise approach;. The variables were: the estimated extent of bias (table 7); the overall size of the study (table 9), expressed as its logarithm to the base 10; whether or not the study was obtained from a systematic search of the literature (0=no; 1=Yes; table 10); the year in which the study was carried out (table 12); the year of birth of the subjects (table 13); and the age of the subjects (table 14). All effects (except the dummy variable for systematic search) were expressed as single degrees of freedom representing linear components of the variables. Missing values were replaced by population means.

Stepwise analysis showed that only two variables were significant predictors of the proportion of left-handers, at the 0.05 level of significance. The first variable entering the equation was the age of the subjects $t(98)=-2.633$, $p=.0098$, with a slope of -1.058 % per decade (SE .4018). The second variable entered was the logarithm of the sample size ($t(97)=-2.413$, $p=.0177$), with a slope of -1.942 % per log unit. The only other variables then approaching significance for entry on the next step were the dummy for systematic search ($t(96)=1.753$, $p=.0827$) and the linear trend of bias ($t(96)=1.640$, $p=.1043$).

Since age, year of birth and year of study show some degree of multicollinearity, hierarchical analyses were conducted to find whether one was particularly important. Year of study did not seem to be of any importance, being non-significant when entered after age ($t(96)=1.54$, $p=.127$), although age was still significant when entered after year of study ($t(96)=-2.57$, $p=.0117$). Age and year of birth were each significant when entered first ($t(97)=-2.57$, $p=.0117$ and $t(97)=2.399$, $p=.0183$ respectively), although neither was significant when entered after the other ($t(96)=-1.476$, $p=.143$ and $t(97)=1.031$, $p=.305$ respectively). It must be concluded that although age is a better predictor than year of birth, this difference is of only marginal importance, and there is no sense in which age shows a significantly closer relationship than does year of birth. In contrast, year of study is significantly less correlated with the percentage of left-handedness than is age or year of birth.

Sex differences.

In 65 study populations the sex of the subjects was known, and in 63 study populations both male and female subjects were studied. Figure 2 shows, for each of those study populations, the difference in incidence of left-handedness between males and females expressed as a percentage of the incidence in females (100x(Males-Females)/Females). It can be seen that in 52 of the 63 study populations there was an excess of male left-handers compared with only 9 studies in which there was an excess of female left-handers, and 2 in which the incidences were the same in the two sexes.

Tables 2 to 15 summarise the overall incidence of left-handedness in males and females and the proportional difference in incidence between the sexes in relation to the background variables in which we have been interested. Only two measures showed any obvious relationship to the size of the sex difference. In table 9 it appears that the sex difference is larger in the studies with the largest sample size, and in table 11 it seems that the sex difference is largest in multivariate studies in which many variables apart from handedness were being assessed. Otherwise the size of the sex difference showed no obvious relationship to the way in which the study had been carried out, the methods of measuring handedness, the year of study or age or year of birth of subjects, or their geographical location. Statistical testing showed no significant effects of any of the moderator variables upon the size of the male-female difference: Table 3: $F(4,56)=1.361$, NS; Table 4: $F(4,25)=2.04$, NS (linear $F(1,25)=2.07$, NS); Table 5: $F(2,27)=1.27$, NS (Linear $F(1,27)=1.40$, NS); Table 6: $F(3,59)=.907$, NS); Table 7: $F(3,59)=.182$, NS (Linear $F(1,59)=.381$, NS); Table 8: $F(3,18)=.191$, NS (Linear $F(1,18)=.388$); Table 9: $F(3,59)=.127$ (Linear $F(1,59)=.004$, NS); Table 10: $F(2,60)=.925$, NS; Table 11: $F(3,59)=.566$, NS; Table 12: $F(3,59)=.906$, NS (Linear $F(1,59)=.36$, NS); Table 13: $F(4,44)=.655$, NS (Linear $F(1,42)=..359$ NS); Table 14: $F(5,41)=2.52$, $p=.045$ (Linear $F(1,41)=.017$, NS); Table 15: $F(4,58)=.482$, NS).

Multivariate analysis of sex differences. Since none of the moderator variables shown in tables 3-15 had shown significant effects upon the size of the sex difference (and the closest to significance was the linear effect of the number of questionnaire items - table 4 - with $p=.162$) then it is not possible that any of them would show significant effects within a stepwise multiple regression. It must be concluded that none of the moderator variables were associated with the size of the difference in incidence in males and females.

Discussion.

This meta-analysis, which has examined the handedness of over a quarter of a million subjects, has found that overall the best estimate of the incidence of left-handedness is 7.78%, a figure remarkably close to the theoretical estimate derived from genetic studies by McManus (, 1985a), and to the value of 7.4% suggested by Coren and Porac (, 1977c) from their study of works of art over five millennia. Since completing our meta-analysis we have also become aware of the very large study of handedness by Carrothers (, 1947) which looked at 225,000 school-children in Michigan: it found an overall incidence of left-handedness of 8.2%, with a 34.3% higher incidence in males than females, both results being remarkably similar to those found in the present study.

Analysis of the incidence of left-handedness according to the type of measuring instrument suggests that there is little difference between incidences derived from lengthy, detailed inventories and from simple questions about the hand used for writing. The incidence of left-handedness therefore seems to be robust across measurement methods. One possible source of bias concerns the size and the response rate of studies: smaller studies, and those with lower response rates have somewhat higher incidences of left-handedness, possibly because left-handers are more likely to respond in such situations, as has been demonstrated by Cornell and McManus (, 1992). A similar difference is found in studies in which handedness is manifestly the purpose of the study, as compared with those in which it is merely one variable amongst many others. Stepwise regression suggests that the latter effect is mainly secondary to the effect of study size.

Of particular theoretical interest for understanding the origins of left-handedness is our finding of a lack of obvious difference in the incidence of handedness as a function of the continent in which they live. A genetic theory in which handedness was under strong selective pressure, being maintained by a balanced polymorphism, would expect such a result.

The differences between age groups and birth cohorts are difficult to interpret, in the absence of clear data suggesting that one effect is secondary to the other. This failure probably reflects a poor power of our study, with only 100 studies, to distinguish such effects. Either the age or the year of birth effect could be interpreted as older subjects (who tend to be born earlier), and who have lower incidences of left-handedness, being subject to greater degrees of reporting bias, for one reason or another. Alternatively there may be genuine differences in handedness between age groups or birth cohorts. Studies comparing the influence of age upon hand preferences for different tasks suggest that some tasks, such as picking up a glass show trends towards greater right-hand usage than do tasks such as writing a letter or cutting with scissors (Porac, C., Izaak, M., & Rees, L., 1990), suggesting that social or other pressures may be partly responsible for age-related changes. Within right-handers there is also evidence that the degree of handedness, as assessed by a peg-board task, becomes greater with age (Weller, M. P. I. & Latimer-Sayer, D. T., 1985). Taken together these results allow the possibility that apparent age-related or cohort-related changes in incidence of handedness may reflect differences in interpretation of questions, or of different criteria for self-description as right or left-handed. There is a striking absence of adequate longitudinal studies of adult handedness, but we suspect that they would show that the direction of adult handedness is relatively fixed (although its degree may well change). Taken together we do not feel at present that the effects of age upon handedness are sufficient to support the controversial hypothesis of Halpern and Coren (, 1990b) that left-handers have an increased mortality compared with right-handers, and hence are less prevalent in older age groups. A principal reason for being sceptical of that result is that in the data of

Halpern and Coren (, 1988b) there is simply no statistically significant difference in the life-expectancy of the right and left-handers using a conventional t-test (and the meaning of the difference found in their Kolmogorov-Smirnov test then becomes difficult to interpret). Subsequent re-analysis of the Halpern and Coren data by Anderson (, 1989b) has complicated matters by suggesting that longevity may interact with date of birth, there being no overall difference in survival of right and left handers. At present perhaps the best interpretation would therefore be that older subjects or those from earlier birth cohorts differ from younger subjects in the manner in which they respond to handedness questionnaires, thereby producing some form of response bias.

The sex differences found in this study are of some interest. Many researchers have linked lateralisation and sex differences, although the nature of the relationship is far from clear (see for instance the published commentaries on the paper of McGlone (, 1980b)). Our meta-analysis leaves little doubt that as measured in most studies of handedness there is an excess of male left-handers over female left-handers. The effect is however relatively small, with about five male left-handers for every four female left-handers. The lack of any obvious relationship with our assessments of methods of measurement methods, response rates, or the extent of bias in collecting subjects, make it unlikely that the effect is the result of any obvious systematic error in data collection. Similarly the lack of a relationship to the age of subjects, to their date of birth, to the year of the study, or to the geographical location rule out many possible explanations in terms of cultural biasses. At present we therefore remain agnostic about the origin of these differences, the reality of which seems difficult to dispute. Nevertheless we do note that Porac, Coren and Searleman (, 1983b) (see also Porac, Ress and Buller (, 1990c)) did find that women were significantly more likely than men to report having being forced to change their handedness (principally from left to right); they suggest, perhaps rightly, that this could explain the overall difference in handedness between the sexes.

Taken overall our impression of this large literature (of which we have undoubtedly only sampled a sub-set) is that although impressive in size and range, with many subjects having been assessed for handedness, the literature is also disappointing in the lack of consistency of methods and approaches between studies, which often precludes any more sophisticated meta-analysis. Data are often poorly presented, with few cross-tabulations, which produces inevitable difficulties in extracting detailed information. The problem is compounded by studies which use unusual or idiosyncratic measurement methods or eccentric methods of classification or reporting which bear little relation to other studies. As an example, we had to discard 15 studies which *only* reported their data in terms of the right, mixed and left classification of Annett (, 1967). We do not object to this classification being used as such; it has a theoretical rationale, and it may well be of use. However we feel that reporting *only* in those terms limits the uses to which the data may be put. We note particularly that Annett herself (e.g. (, 1973b; , 1979c)) not only reports her data in terms of Right, Mixed and Left but also in terms of the hand used for writing, thereby allowing the data to be included in a meta-analysis such as the present one.

Much confusion in the literature seems to results from a confusion between the concepts of *direction* and *degree* of handedness (McManus, I. C., 1983b), which are confounded by studies which merely report the mean laterality score across the whole range of subjects, or which report in terms of three categories such as right, mixed and left in which the mixed category is broadly defined. Frequently the impression is that the term 'mixed' should be replaced by the term 'a mixture', since mixed handers are in reality a mixture of weak right-handers and weak left-handers in indeterminable proportions. The concept of degree of handedness is an important one in laterality, which is only just beginning to be explored (e.g. McManus *et al* (, 1988c), and we are keen to see further analyses of its properties. However in this review we have found ourselves completely unable to carry out any realistic meta-analysis of degree of handedness due to its limited and inadequate reporting in studies, and due to its confounding with other measures. That problem would be avoided if studies were to report the results of measures of degree of handedness in a standardised form.

In general we were impressed by the results of the larger studies of handedness simply because the studies had of necessity used fairly straightforward measures of handedness, and had a high response rate because of the method of sampling; examples that particularly come to mind are those of the Scottish scholastic survey (Scottish Council for Research in Education, 1953) in school children, of Komai and Fukuoka (, 1934), also in schoolchildren, and of Karpinos and Grossman (, 1953) in servicemen. We must therefore recommend that in general unless degree of handedness or some detailed analysis of specific items is the particular interest of studies, that simple, easily interpretable questions should be used.

In the interests of further analysis of handedness we therefore recommend that the following methods of measuring and reporting handedness are used, wherever possible. They are described in detail, along with scoring methods, in Appendix 1.

Recommendations on the measurement of handedness.

a. Handedness should be assessed and reported using one of the following methods:

i. In Western populations, or in other groups for whom forced changing of writing hand as a result of cultural pressure is now relatively unusual, the best question is "Which hand do you usually use for writing?". This question avoids many of the ambiguities of asking "Are you right or left-handed?", in which differences of criterion (all / most / some / any tasks left-handed?) can confound results. For a simple incidence study the two replies to the writing hand question,"Right Left", are sufficient to obtain accurate results (Method 1.a). If some indication of degree of handedness or of ambidexterity is required then the question can have a five-point response scale, "Always right / Usually right / Either / Usually left / Always left" (Method i.b). The data in table 16, in which such a question was used shows that in fact very few 'either' responses are obtained; however 'usually' replies are fairly frequent and, interestingly, differ in frequency between males and females, being significantly higher in females. The overall incidence of left and right handedness does not differ between the sexes when weak and strong responses are combined. We do not recommend in any circumstances the use of three responses of the form "Right/Either/Left", since the method confounds weak handedness with ambidexterity.

ii. In groups where cultural pressure to use the right hand is possible or likely, we recommend that method 1 described above is used (so that full comparative data are available), and that in addition a detailed assessment of cultural pressures to change is also included. Porac *et al* (, 1986c) have reported a questionnaire which assesses cultural pressures. At present there is little experience of its use, and until more information is available it is difficult to assess it more formally. At present we do not know of any simple form of question which can be used reliably to modify the question of method i to allow correction of handedness for forced change.

iii. If it is desired to measure degree of handedness then the most well-established of the handedness inventories is undoubtedly the Edinburgh Inventory (Oldfield, R. C., 1971), and we recommend that it should be used (Method ii). It is not necessarily the very best of measuring instruments, but it does have the advantages of being used frequently (albeit often with some minor modification, as we ourselves recommend). As was stated by its originator (Oldfield, R. C., 1971):

> "Doubtless the inventory is not ideal, but it is simple and provides *one* quantitative measure of handedness backed by a known distribution of values in a reasonable sized normal population." (emphasis in original).

A laterality quotient (LQ) should be calculated in the conventional manner, and then results presented in terms of particular bands of scores. We recommend that simple left- and right-handedness should be defined as $LQ \leq 0$ and $LQ > 0$ respectively. Degree of handedness should always be presented by categorising subjects as weak or strong right-and left-handers. If it is wished to sub-divide categories further then this should be done by dividing these groups into two (to give eight equal categories),etc., so that it is then possible to recombine groups for comparison across studies. In addition means and Sds of laterality quotients can be reported, in which case they should be reported separately for right and left-handers (defined as $LQ > 0$ and $LQ \leq 0$ respectively). The overall mean and SD of the laterality quotient do not provide useful information since they confound direction and degree of handedness.

b. In all studies the incidence of handedness should be reported separately for males and females, using whatever method of assessment has been decided upon.

c. Distributions of laterality coefficients are useful only as an additional form of reporting of incidences; they should not be used as a substitute for the methods described above.

Appendix 1 sets out in detail the questions that we recommend for assessment of handedness, the calculation of scores, and their methods of reporting. In making these recommendations we do not wish to be prescriptive or to restrict unnecessarily the ways in which handedness may be assessed. However we suggest that as a minimum requirement one or other of the methods described above should normally be included and reported in any study of laterality; other measures may then be included additionally according to the theoretical wishes or the research needs of the investigators.

Appendix 1: Recommended methods of measuring handedness.

For each method the manner of calculation of the proportion of left-handers (pL) is indicated, along with the method of calculating the proportion of weak left-handers (pWL), weak right-handers (pWR) and weak handedness overall (pW). Whatever method of assessment is used, results of studies should always be reported separately for males and females.

Method i.a: "Which hand do you normally use for writing?"

Responses	*Number of replies*
'Right'	R
'Left'	L

Scoring

$$pL=\frac{L}{R+L}$$

pW, pWR and pWL cannot be calculated.

Method i.b: "Which hand do you normally use for writing?"

Responses	*Number of replies*
'Always right'	R
'Usually right'	r
'Either'	e
'Usually left'	l
'Always left'	L

Scoring All studies should report pL, pWR, PWL and pW.

$$pL=\frac{L+l+e}{R+r+e+l+L}$$

$$pWR=\frac{r}{r+R}$$

$$pWL=\frac{l}{l+L}$$

$$pW=\frac{r+e+l}{R+r+e+l+L}$$

Method *ii.* A recommended modification of the Edinburgh Handedness Inventory (Oldfield, 1971) is presented in Appendix 2. The original questionnaire has been modified principally in that five response categories have been allowed for each of the responses. The questions on eye and foot preference have been omitted from the present version since it is only concerned with handedness.

If it is desired to use a laterality questionnaire with more than the 10 items included in the Edinburgh Inventory then' it is recommended that the 10 items of the Edinburgh should always be included within the longer inventory. Results should be reported separately for the 10 items of the Edinburgh inventory in the method described below, so that comparability is maintained between studies.

More complex inventories can usually be analysed in an analogous fashion to that described below for the Edinburgh inventory. and normally pL, pWR and pWL should be reported for the lengthier questionnaire. If a more detailed subdivision of degree of handedness is required, beyond the categories of weak and strong, it is suggested that further category boundaries should be binary sub-divisions of previous categories i.e. histogram bin divisions should be 0, (-50, 0, +50), (-75, -50, -25, 0, +25, +50, +75), etc, to give 2, 4, 8, categories, etc.. Such a division always allows other less detailed classifications to be re-calculated from the data.

Scoring. For an individual subject let R, r, e, 1 and L be the total number of 'Always right', 'Usually right', . 'Either', 'Usually left' and 'Always left' responses (if all questions have been answered, R+r+e+l+L=lO). All studies should report pL, pWL and pWR; other measures are optional.

For each subject calculate a laterality quotient, LQ:

$$LQ=\frac{100.(R+\frac{r}{2}-\frac{l}{2}-L)}{R+r+e+l+L}$$

Let $n(...)$ be the total number of subjects satisfying a condition, and let N be the total number of subjects, then:

$$pL=\frac{n(LQ\leq 0)}{N}$$

$$pWR=\frac{n(50>LQ>0)}{n(LQ>0)}$$

$$pWL=\frac{n(-50>LQ>0)}{n(LQ>0)}$$

$$pW=\frac{n(-50<LQ<50)}{N}$$

If means and standard deviations of the LQ are to reported then they should be given separately for right-handers (LQ > 0) and for left-handers (LQ ≤ 0).

If the continuum of laterality scores is to be further sub-divided then it can be done as in the text, into 8, 16 classes, etc..

Appendix 2: Recommended handedness inventory.

Handedness inventory

Please indicate your preferences in the use of a hand for the following activities by putting a tick in the appropriate column.

Some of the activities require both hands. In these cases the part of the task,or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions and only leave a blank if you have no experience at all of the object or task.

	Always Left	Usually Left	Either	Usually Right	Always Left
1. Writing					
2. Drawing					
3. Throwing					
4. Scissors					
5. Toothbrush					
6. Knife (without fork)					
7. Spoon					
8. Broom (upper hand)					
9. Striking match (holding the match)					
10. Opening box (holding the lid)					

Table 1: A summary of the studies included in the meta-analysis.

Study	Subjects	How found	Estimated bias	Response rate	Assessment method	Handedness criterion	Final category	Sub-groups	%Left-handed: Total	Males	Females
Ramaley, 1913 (Ramaley, F., 1913)	1130 American students; 610 parents	Students in lectures; parents by questionnaire	3	-	'Are you R/L handed?'	Answer to question	R-L	Parents Offspring	8.0 15.7	- -	- -
Smith, 1917 (Smith, L. G., 1917)	2055 American school children	Total population of 3 schools	2	100%	Not specified	-	R-L	-	5.0	5.5	4.5
Chamberlain, 1928 (Chamberlain, H. D., 1928)	7714 American children; 4354 parents	Complete 1927 Freshman class at Ohio State University, and families	2	100%	'Are you R/L handed?'	Answer to question	R-L	Parents Offspring	3.6 4.8	4.1 5.3	2.9 3.8
Koch *et al.*1933 (Koch, H. L. et al., 1933)	201 American students	Random sample form 1928 year at Texas University	2	-	Written questionnaire	LQ < 0	R-L	-	7.6	-	-
Komai and Fukuoka, 1934 (Komai, T. & Fukuoka, G., 1934)	16947 Japanese children	Grades 1-8 of 20 primary schools	2	-	Written questionnaire	Any items L	R-L	-	11.5	12.3	10.6
Rife, 1940 (Rife, D. C., 1940)	3542 American children and adults	Captive whole group of students and their families	2	-	Written questionnaire	Any items L	R-L	-	7.5	-	-
Rife and Schonfield, 1944 (Rife, D. C. & Schonfield, M. D., 1944)	325 American students	Self-selected volunteers	2	-	Written questionnaire	Any items L	R-L	-	11.7	-	-
Karpinos and Grossman, 1953 (Karpinos, B. D. & Grossman, H. A., 1953)	12159 American men	Random sample; all army recruits (accepted and rejected) on 18th, 28th and 30th June 1952	1	100%	'Are you R/L handed?'	Answer to question	R-L	-	8.8	8.8	-
Scottish Council for Research in Education, 1953; see Clark, 1957	72238 Scottish school children	Complete population; all 10-11 year old	1	100%	Writing hand	Writing hand	R-L	-	5.6	6.7	4.4

(Table continued)

24

Study	Subjects	How found	Estimated bias	Response rate	Assessment method	Handedness criterion	Final category	Sub-groups	%Left-handed: Total	Males	Females
(Clark, M. M., 1957)		children in Scotland in 1953									
Clark, 1957 (Clark, M. M., 1957)	5790 Scottish school children	Captive whole group; 8 Glasgow schools	1	100%	Writing hand	Writing hand	R-L	-	7.0	8.0	5.9
Merrell, 1957 (Merrell, D. J., 1957)	123 American adults	Randomly selected university students	3	-	Writing hand	Writing hand	R-L	-	4.1	4.2	3.9
Falek, 1959 (Falek, A., 1959)	10236 American adults	Parents of children at 6 randomly selected schools	1	47%	Written questionnaire	LQ < 0	R-L	-	3.5	3.9	3.1
Collins, 1961 (Collins, E. H., 1961)	943 male American students	Captive whole group; Dental and medical students at University of Illinois, 1954-59	3	-	Written questionnaire	Any item L	R-M-L	L L+M	9.8 22.9	9.8 22.9	- -
Beckman and Elston, 1962 (Beckman, L. & Elston, R., 1962a)	981 Swedish adults	Random sample	2	-	Not specified	-	R-L	-	5.4	5.1	5.7
Crovitz and Zener, 1962 (Crovitz, H. F. & Zener, K., 1962b)	1569 American students	Self-selected volunteers	3	-	Written questionnaire	Laterality score	R-L	-	10.7	11.2	10.2
Pelecanos, 1969 (Pelecanos, M., 1969)	2144 Greek children	From 9 randomly selected primary schools in Thessaloniki	2	-	Performance of 5 tasks (e.g. cutting, catching)	Any item L	R-L	-	10.4	11.2	9.3
Annett, 1970 (Annett, M., 1970)	2322 British students and adults	Random sample; university students and servicemen	3	-	Written questionnaire	-	R-M-L	L L+M	4.3 31.7	- -	- -
Oldfield, 1971 (Oldfield, R. C., 1971)	1109 British students	Self-selected volunteers; first year students at several British	2	-	Written questionnaire	LQ < 0	R-L	-	7.4	10.0	5.9

(Table continued)

Study	Subjects	How found	Estimated bias	Response rate	Assessment method	Handedness criterion	Final category	Sub-groups	%Left-handed: Total	Males	Females
		universities									
Dawson, 1972 (Dawson, J. L. M. B., 1972)	95 Aborigines; 204 Sierra Leone Temnes	Random sample	3	-	Performance of 3 tasks (writing, receiving object, cutting)	2 or more items L	R-L	Aborigines Temnes	10.5 3.4	10.7 3.8	5.9 0.0
Annett, 1973 (Annett, M., 1973b)	3644 British students	Self-selected volunteers; questionnaires distributed in class and by post	2	-	'Are you R/L handed?'	Answer to question	R-L	-	11.6	11.8	11.5
Newcombe and Ratcliff, 1973 (Newcombe, F. & Ratcliff, G., 1973a)	823 British adults	Random sample (control subjects)	3	-	Written questionnaire	Any item L	R-M-L	L L+M	3.2 20.0	3.7 26.2	2.6 13.8
Rhoads and Damon, 1973 (Rhoads, J. G. & Damon, A., 1973)	1352 Solomon Island adults	Random sample; cross-cultural study	4	-	'Are you R/L handed?'	Answer to question	R-L	-	2.8	-	-
Briggs and Nebes, 1975 (Briggs, G. G. & Nebes, R. D., 1975b)	1599 American students	Captive whole group; all psychology students over two years at a university	3	-	Written Questionnaire	Laterality score	R-M-L	L L+M	9.1 14.4	8.9 14.6	9.4 14.2
Newcombe *et al.*1975 (Newcombe, F. G. et al., 1975)	928 British adults	Self-selected volunteers from a group of	2	90%	Written questionnaire	Any item L	R-L	-	6.4	8.0	4.7

(Table continued)

26

		Oxfordshire villages									
Annett, 1976 (Annett, M., 1976)	804 British students	Captive whole group; class at Open University summer school	2	-	Verbal questionnaire	-	R-L	-	7.6	-	-
Hardyck, Petrinovich and Goldman, 1976 (Hardyck, C., Petrinovich, L. F., & Goldman, R. D., 1976b)	7688 American children	Captive whole group; total population of school children in a medium-sized community	2	-	Performance of 3 tasks (writing, cutting, holding tube to eye)	Any item L	R-L	-	9.6	10.5	8.7
Hatta and Nakatsuka, 1976 (Hatta, T. & Nakatsuka, Z., 1976d)	1199 Japanese adults	Random sample; subjects obtained from offices and colleges	3	-	Written questionnaire	Laterality score	R-L	-	3.1	4.3	2.3
Heim and Watts, 1976 (Heim, A. W. & Watts, K. P., 1976c)	2165 British children and students	Random sample in schools and colleges	3	-	Writing hand	Writing hand	R-L	-	9.4	11.3	7.5
Fleminger, Dalton and Standage, 1977 (Fleminger, J. J., Dalton, E., & Standage, K. F., 1977)	800 British adults	Random sample; control group drawn from Dental Department at Guy's Hospital	4	-	Written questionnaire	Writing hand	R-L	-	8.8	-	-
Gur and Gur, 1977 (Gur, R. E. & Gur, R. C., 1977)	200 American adults	Random sample; control group drawn from workers and non-psychiatric patients	4	-	Written questionnaire	Laterality score	R-L	-	11.0	16.0	6.0
Schwartz, 1977 (Schwartz, M., 1977)	584 Canadian students	Self-selected volunteers obtained in university classes	2	-	Written questionnaire	Laterality score	R-L	-	10.1	-	-
Hicks, Pellegrini and Evans, 1978 (Hicks, R. A., Pellegrini, R. J., & Evans, E. A., 1978)	728 American students	Captive whole group; University freshmen	3	-	Written questionnaire	Laterality score	R-L	-	8.5	11.2	5.8
Kobyliansky, Micle and Arensburg, 1978 (Kobyliansky, E.,	1081 Israeli males	Random sample	4	-	'Are you R/L	Answer to question	R-M-L	Middle East R Middle East R+M	4.2 6.8 9.8	4.2 6.8 9.8	- - -

(Table continued)

Micle, S., & Arensburg, B., 1978)					handed?'			North Africa R North Africa R+M Europe R Europe R+M	10.4 13.3 16.2	10.4 13.3 16.2	- - -
Peters, 1986 (Peters, M., 1986)	5910 Canadian children	Captive whole group of schools in 3 different districts	2	100%	Writing hand	Writing hand	R-L	-	11.0	11.9	10.0
Searleman, Tweedy and Springer, 1979 (Searleman, A., Tweedy, J., & Springer, S., 1979b)	847 American students	Captive whole group of university students	3	-	'Are you R/L handed?'	Answer to question	R-M-L	L L+M	13.5 16.5	13.8 17.2	13.3 16.1
Silverberg, Obler and Gordon, 1979 (Silverberg, R., Obler, L. K., & Gordon, H. W., 1979)	1171 Israeli children	Captive whole group; all children in last 3 grades of 4 randomly selected schools	2	-	Written questionnaire	LQ < 0	R-L	-	10.2	8.6	11.8
Teng *et al.* 1979 (Teng, E. L., Lee, P-H., Yang, K-S., & Chang, P. C., 1979a)	4143 Chinese students and children	Captive whole group; school and university classes	2	-	Written questionnaire	LQ < 0	R-L	-	4.5	6.0	3.0
Coren and Porac, 1980 (Coren, S. & Porac, C., 1980)	2761 Canadian adults	Self-selected volunteers contacted by postal questionnaire	4	28%	Written questionnaire	LQ < 0	R-L	-	10.9	11.4	10.4
Dusek and Hicks, 1980 (Dusek, C. D. & Hicks, R. A., 1980)	600 American children	Random sample	4	-	Written questionnaire	Laterality score	R-L	-	9.2	9.1	9.2
Hicks and Dusek, 1980 (Hicks, R. A. & Dusek, C. M., 1980)	578 American children	Random sample	3	-	Written questionnaire	Laterality score	R-M-L	L L+M	8.4 16.8	- -	- -

(Table continued)

Hicks *et al.* 1980 (Hicks, R. A., Dusek, C., Larsen, F., Williams, S., & Pellegrini, R. J., 1980)	1501 American students	Captive whole group; freshmen at university	2	-	Written questionnair e	Laterality score	R-M-L	LL+M	6.812.6	--	--
Jones and Bell, 1980 (Jones, B. & Bell, J., 1980a)	299 Canadian students	Captive whole group; all first year psychology and engineering students at a university	3	-	Written questionnair e	LQ < 0	R-L	-	12.2	12.7	12.7
McFarland and Anderson, 1980 (McFarland, K. & Anderson, J., 1980)	600 British students	Random sample from 2 schools and 2 universities	3	-	Written questionnair e	Writing hand	R-L	-	9.3	10.4	8.1
Tan and Nettleton, 1980 (Tan, L. E. & Nettleton, N. C., 1980)	942 Australian students and children	Random sample	2	-	Written questionnair e	Laterality score	R-L	-	11.7	13.6	10.7
Birkett, 1981 (Birkett, P., 1981c)	125 British subjects	Self-selected volunteers from schools, colleges and the public	4	-	Written questionnair e	LQ < 0	R-L	-	41.6	38.9	43.7
Hebben, Benjamins and Milberg, 1981 (Hebben, N., Benjamins, D., & Milberg, W. P., 1981)	191 American children	Random sample	2	-	Verbal questionnair e	Laterality score	R-L	-	9.0	9.6	8.2
Leiber and Axelrod, 1981 (Leiber, L. & Axelrod, S., 1981a)	15767 American students and relatives	Self-selected volunteers who also reported on first degree relatives	3	-	'Are you R/L handed?'	Answer to question	R-M-L	L L+M	8.6 11.0	9.8 12.9	7.3 9.0
Mascie-Taylor, 1981 (Mascie-Taylor, C. G. N., 1981)	386 British adults	Captive whole group of 193 couples from a single housing estate	1	100%	Writing hand	Writing hand	R-L	-	8.0	8.8	7.3
McManus, 1981, unpublished	340 British students	Captive whole group of applicants to	2	92%	'Are you R/L handed?'	Answer to question	R-L	-	10.3	10.0	10.7

(Table continued)

		medical school									
Porac and Coren, 1981 (Porac, C. & Coren, S., 1981d)	5147 Canadian adults	Self-selected volunteers, sent questionnaires by post	4	26%	Written questionnair e	LQ < 0	R-L	-	11.8	13.5	9.9
Ashton, 1982 (Ashton, G. C., 1982b)	2027 Hawaiian children and parents	Random sample of families for the Hawaii Family Study of Cognition	3	-	Writing hand	Writing hand	R-L	Parents Children	7.1 10.5	7.1 11.9	7.1 9.1
Bonvillian, Orlansky and Garland, 1982 (Bonvillian, J. D., Orlansky, M. D., & Garland, J. B., 1982)	210 American students	Self-selected volunteers; university students acting as controls	3	-	Written questionnair e	Laterality score	R-L	-	7.1	-	-
Provins, Milner and Kerr, 1982 (Provins, K. A., Milner, A. D., & Kerr, P., 1982c)	1966 British and Australian students	Self-selected volunteers: students at six universities	2	100%	Written questionnair e	LQ < 0	R-L	-	9.5	11.4	7.8
Nachson, Denno and Aurand, 1983 (Nachson, I., Denno, D., & Aurand, S., 1983)	7364 American children	Randomly selected for the Philadelphia Collaborative Perinatal Project (1959-1966)	1	-	Writing hand	Writing hand	R-L	-	11.9	13.3	10.4
Porac, Coren and Searleman, 1983 (Porac, C., Coren, S., & Searleman, A., 1983b)	1341 Canadian parents and children	Self-selected volunteers, sent questionnaires by post	4	23%	Written questionnair e	Laterality score	R-L	Parents Children	7.1 16.6	7.6 14.6	6.7 18.4
Salmaso and Longoni, 1983 (Salmaso, D. & Longoni, A. M., 1983a)	1694 Italian students	Self-selected volunteers from secondary schools and universities	3	-	Written questionnair e	LQ < 0	R-L	-	6.4	-	-

(Table continued)

30

Shimizu and Endo, 1983 (Shimizu, A. & Endo, M., 1983)	4282 Japanese students	Random sample of five senior schools	2	96%	Written questionnaire	Laterality score	R-NR	-	11.0	12.0	10.0
Spiegler and Yeni-Komshian, 1983 (Spiegler, B. J. & Yeni-Komshian, G. H., 1983)	1816 American students	Random sample	2	-	Writing hand	Writing hand	R-L	-	13.8	15.2	12.6
Buchtel and Rueckert, 1984 (Buchtel, H. A. & Rueckert, L., 1984)	740 American students	Captive whole group of psychology students at a university	3	-	Written questionnaire	-	R-L	-	13.4	13.7	13.1
Gillberg, Waldenström and Rasmussen, 1984 (Gillberg, C., Waldenström, E., & Rasmussen, P., 1984)	985 Swedish children	Random sample of school children in a single town	2	-	Writing hand	Writing hand	R-L	-	9.2	10.9	7.4

Plato, Fox and Garruto, 1984 (Plato, C. C., Fox, K. M., & Garruto, R. M., 1984)	705 American adults	Randomly selected for the Baltimore Longitudinal Study of Aging	3	-	Performance of unskilled task	Writing hand	R-L	-	5.5	6.9	4.1
Rymar *et al.* 1984 (Rymar, K., Kameyama, T., Niwa, S-I., Hiramatsu, K-I., & Saitoh, O., 1984)	725 Japanese children	Randomly selected classes form 6 schools in Tokyo	1	100%	Performance of 7 tasks (e.g. writing, throwing, etc.)	Laterality score	R-M-L	L L+M	3.7 9.8	- -	- -
Segal, 1984 (Segal, N. L., 1984)	1577 American students	Captive whole group of all students sitting exams at a single centre on one	1	100%	Writing hand observed	Writing hand	R-L	-	9.6	10.0	9.0

(Table continued)

		day									
McManus, 1985 (McManus, I. C., 1985a) - ICM1	613 British students and relatives	Self-selected volunteers at university, who also reported on siblings and parents	3	50%	Writing hand	Writing hand	R-L	Parents Children	6.7 9.7	- -	- -
McManus, 1985 (McManus, I. C., 1985a) - ICM2	837 British students and relatives	Self-selected student volunteers and their parents, who reported on siblings, aunts, uncles and grandparents	3	20%	Writing hand	Writing hand	R-L	Grandparents Parents Children	3.2 4.5 9.8	- - -	- - -
Tapley and Bryden, 1985 (Tapley, S. M. & Bryden, M. P., 1985)	1523 Canadian students	Self-selected volunteers: psychology students at a university	2	-	Written questionnair e	Laterality score	R-L	-	11.7	13.0	10.8
Beukelaar and Kroonenberg, 1986 (Beukelaar, L. J. & Kroonenberg, P. M., 1986)	1996 Dutch adults	Self-selected volunteers, sent questionnaire by post	3	67%	'Are you R/L handed?'	Answer to question	R-L	-	16.6	-	-
McManus, 1986, unpublished.	2028 British students	Captive whole group: all students applying to medical school	2	94%	'Are you R/L handed?'	Answer to question	R-L	-	11.0	11.1	11.0
Peters, 1986 (Peters, M., 1986)	2194 German children	Random sample of school children	2	-	Written questionnair e	-	R-L	-	9.0	10.6	7.4
Porac, Coren and Searleman, 1986 (Porac, C., Coren, S., & Searleman, A., 1986c)	650 Canadian students	Captive whole group	2	-	Written questionnair e	Laterality score	R-L	-	11.6	-	-
Strauss, 1986 (Strauss, E., 1986)	197 Canadian students	Self-selected volunteers	3	-	Written questionnair e	Laterality score	R-NR	-	11.8	-	-
Chapman and Chapman, 1987	2931 American	Captive whole group of	3	-	Written questionnair	Laterality score	R-L	-	9.0	9.4	8.6

(Table continued)

(Chapman, L. J. & Chapman, J. P., 1987)	students	psychology students at a university			e						
Chapman, Chapman and Allen, 1987 (Chapman, J. P., Chapman, L. J., & Allen, J. A., 1987)	311 American students	Randomly selected psychology students at a university	3	-	Written questionnair e	Laterality score	R-L	-	20.3	-	-
Payne, 1987 (Payne, M. A., 1987)	201 Nigerian students	Self-selected volunteers at a university	2	-	Written questionnair e	LQ < 0	R-L	-	10.0	-	-
Pipe, 1987 (Pipe, M., 1987)	239 New Zealand children	Randomly selected control group	2	-	Performance of unskilled task	Laterality score	R-NR	-	18.0	-	-
Schacter, Ransil and Geschwind, 1987 (Schacter, S. C., Ransil, B. J., & Geschwind, N., 1987)	1117 American adults	Randomly selected professionals	2	41%	Written questionnair e	LQ < 0	R-L	-	12.4	-	-
Searleman, Tweedy and Springer, 1979 (Searleman, A., Tweedy, J., & Springer, S., 1979b)	277 American students	Self-selected students acting as controls	3	-	Written questionnair e	Laterality score	R-L	-	12.6	14.7	10.8
Smith, 1987 (Smith, J., 1987)	350 British adults	Self-selected volunteers acting as controls	2	-	Written questionnair e	Laterality score	R-L	-	8.9	11.0	7.0
Cosi, Citterio and Pasquino, 1988 (Cosi, V., Citterio, A., & Pasquino, C., 1988)	178 Italian adults	Self-selected volunteers acting as controls	4	-	Written questionnair e	Laterality score	R-L	-	6.2	5.2	6.7
Ellis, Ellis and Marshall, 1988 (Ellis, S. J., Ellis, P. J., & Marshall, E., 1988)	6097 British adults	Random sample for a General Medical Practice	2	82%	Written questionnair e	LQ < 0	R-L	-	7.9	8.4	9.6
Lansky, Feinstein and Peterson, 1988 (Lansky, L. M., Feinstein, H., & Peterson, J. M., 1988)	2083 American adults	Randomly selected subjects, contacted by telephone survey	1	-	Verbal questionnair e	-	R-L	-	7.2	9.4	5.6
Levander and Schalling, 1988	921 Swedish students	Captive whole group of students	1	100%	Writing hand	Writing hand	R-L	-	8.9	8.0	10.0

(Table continued)

33

(Levander, M. & Schalling, D., 1988)		at a college									
la *et al.* 1989 A. et al., 1989)	266 Colombian students	Random samples of subjects from 2 different towns	4	-	Written questionnaire	LQ < 0	R-L	-	8.7	-	-
al. 1989 (Brito, O., Brito, L. S. ımgartten, F. J. Lins, M. F. C., 1989a)	959 Canadian adults	Self-selected volunteers from colleges, and an engineering company	3	-	Verbal questionnaire	LQ < 0	R-L	-	6.9	8.5	5.3
uis and Bryden, Steenhuis, R. E. en, M. P., 1989)	691 Canadian students	Captive whole group of first year psychology students	2	-	Written questionnaire	LQ < 0	R-L	-	8.4	9.9	6.3
uis and Bryden, Steenhuis, R. E. en, M. P., 1989)	251 Canadian students	Self-selected volunteers in a single psychology class	2	-	Written questionnaire	LQ < 0	R-L	-	8.8	-	-
lbach, de Ruiter Olff, 1989 kelbach, H., de C., & Olff, M., 1989)	167 Dutch students	Random sample of first year university students	3	-	Written questionnaire	LQ < 0	R-M-L	L L+M	10.2 16.8	- -	- -
Manus, 1990, ıpublished	16519 British people	Controls for the National Childhood Encephalopathy Study (NCES); randomly generated from birth register. Reported on by parents who also described siblings, aunts, uncles, and grandparents.	1	70%	'Are you R/L handed?'	Answer to question	R-L	Grandparents Parents Children	5.4 5.2 10.9	5.7 5.7 11.9	5.0 4.7 9.9

(Table continued)

Table 2: the overall incidence of left-handedness in the studies.

The first part of the column marked classification shows the method used (e.g. R-L; right versus left-handed); (R-NR; right versus non-righthanded); and R-M-L (right versus mixed versus left-handedness), and the second part of the column shows the method of calculating the proportion of left-handed subjects (e.g. L/(L+R)). The final row shows the combined data for the first three rows (but not including the fourth row).

Classification	Number of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) -------- F
R-L: L/(L+R)	82	251698	9.0	9.17	7.68	122705	107056	8.44	6.59	28.1
R-NR: NR/(R+NR)	3	4718	11.8	13.60	11.38	2159	2123	12.00	10.00	20.0
R-M-L: L/(R+M+L)	15	28249	8.6	7.89	8.06	4399	2995	8.95	7.93	12.9
R-M-L: (L+M)/(R+M+L)	15	28249	16.2	17.65	15.16	4399	2995	16.69	11.99	39.2
Total: L/(R+L) NR/(R+NR) L/(R+M+L)	100	284665	9.0	9.11	7.78	129263	112174	8.52	6.69	27.4

Table 3:

Incidence of left-handedness in relation to method of assessment of handedness.

Method of assessment of handedness	Numbe r of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) -------- F
Preference by written questionnaire	52	95385	9.2	9.93	8.89	35888	36.83	9.84	8.18	20.3
Preference by verbal questionnaire	3	1954	7.6	7.83	7.37	565	585	8.68	5.78	50.2
Performance of an unskilled task	8	13376	7.1	7.93	8.45	6536	5876	9.21	7.86	17.2
'Are you R/L handed?'	17	67545	8.8	8.68	7.63	32849	17229	7.80	6.17	26.4
Writing hand	18	105169	9.1	8.33	6.89	51905	50884	7.97	5.73	39.1

36

Table 4: Incidence of left-handedness in relation to number of items on questionnaire or inventory.

Number of items on questionnaire	Numbe r of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) -------- F
3-6	10	40130	10.4	9.39	9.08	20103	18914	9.90	8.03	23.3
7-10	16	21246	8.6	10.33	8.01	6492	7342	8.84	7.57	16.8
11-15	18	27498	8.9	9.16	8.31	6341	6488	10.66	9.41	13.3
16-49	4	1751	8.9	9.05	8.17	594	906	10.94	6.16	77.6
50+	4	3059	9.0	8.8	9.15	1279	1378	11.00	7.42	48.2

37

Table 5: Incidence of left-handedness in relation to number of response categories on each item of an inventory.

Number of response categories on questionnaire	Number of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) / F
<5	20	51599	9.0	9.14	8.79	23127	21926	9.72	7.83	24.1
5	27	33033	9.2	10.48	10.41	10424	11545	10.45	9.03	15.7
>5	2	2176	8.3	8.3	9.28	-	-	-	-	-

38

Table 6: Incidence of left-handedness in relation to sampling method for obtaining subjects.

Sampling methods	Number of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) / F
Self-selected volunteers	26	28897	9.8	10.31	10.02	10701	10879	10.80	8.99	20.1
Captive whole group	28	164313	9.1	9.25	7.34	85445	67098	8.19	6.22	31.7
Random sample	39	62409	9.0	8.66	8.05	25723	27141	9.05	7.19	25.9
Indirect reporting by others	7	29046	6.7	6.63	7.39	7394	7056	7.16	5.61	27.6

39

Table 7: Incidence of left-handedness in relation to estimated degree of bias in the selection of subjects.

Estimated degree of bias	Number of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) -------- F
None	10	101443	7.1	6.95	6.04	50682	50036	7.09	4.94	43.5
Slight	42	121862	9.1	9.01	8.55	61822	46312	9.22	7.92	16.4
Possible	35	47607	9.1	9.07	8.79	11417	10914	9.45	7.88	19.9
Probable	13	13573	9.8	11.23	10.19	5342	4912	11.96	10.12	18.2

40

Table 8: Incidence of left-handedness in relation to response rate, if known.

Response rate	Number of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) -------- F
0 - 39%	6	10575	8.5	7.88	10.10	4125	4683	12.20	9.75	25.1
40 - 79%	8	30481	8.2	8.80	6.24	13386	13369	5.63	4.66	25.9
80 - 99%	5	13675	10.3	9.32	9.28	6758	6917	10.01	8.56	13.7
100%	12	115795	7.5	7.12	6.28	65352	49719	7.31	4.90	49.2

41

Table 9: Incidence of left-handedness in relation to sample size in study.

Sample size	Number of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) -------- F
<250	16	2880	9.4	10.70	10.21	1591	1421	10.71	9.20	16.4
250 - 999	37	2415	8.9	9.07	8.64	15664	14537	9.55	8.05	18.6
1000 - 4999	34	75680	9.3	8.74	8.44	44200	47412	9.63	7.66	25.7
> 4999	13	181953	8.6	8.24	7.31	67808	48804	7.71	5.26	42.8

42

Table 10: Incidence of left-handedness in relation to source of study.

Source of study	Number of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) -------- F
Systematic search	48	79630	9.1	10.30	9.16	24106	24991	10.49	8.75	19.9
Secondary references	34	176816	7.8	8.01	7.24	92742	75221	8.12	6.03	34.7
Personal collection/ Unpublished	18	28219	9.4	8.04	7.21	12415	11962	7.65	6.53	17.2

43

Table 11: Incidence of left-handedness in relation to the assessment of the main purpose of the study.

Main purpose of study	Number of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) -------- F
Handedness	57	113791	8.9	9.30	8.00	41721	38256	8.36	7.03	18.9
Lateralisation	20	39749	10.1	9.27	10.00	16192	15748	11.90	10.02	18.8
Other measures	10	13247	9.9	9.10	9.40	6018	5624	10.00	8.02	24.7
Multivariate	13	117878	7.2	8.07	6.63	65332	52546	7.65	5.29	44.6

44

Table 12: Incidence of left-handedness in relation to the year in which the study was carried out (or year of publication if year of study not stated).

Year of study or year of publication	Number of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) / F
1900-39	9	36676	7.5	7.53	8.42	17381	13813	8.81	7.59	16.1
1940-69	11	109412	7.0	7.43	6.02	60395	46370	7.11	4.57	55.6
1970-79	38	61550	9.2	8.46	9.31	23978	24439	10.69	8.80	21.5
1980-89	42	77027	9.2	10.49	8.75	27509	27555	9.53	7.93	20.2

45

Table 13: Incidence of left-handedness in relation to estimated year of birth of subjects.

Year of birth	Number of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) -------- F
Pre-1910	8	27697	4.9	6.43	4.65	13355	11005	4.58	3.36	36.3
1910-39	10	39573	7.8	8.11	9.36	25827	11585	9.71	9.02	7.6
1940-59	26	115129	9.8	8.78	6.41	53324	52627	7.38	5.40	36.7
1960-69	26	6.0345	10.1	11.51	9.96	21302	20327	11.45	9.68	18.3
1970-89	8	8576	9.1	9.67	9.35	3357	3586	11.01	8.60	28.0

Table 14: Incidence of left-handedness in relation to estimated age of subjects at time of study.

Age of subjects	Numbe r of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) -------- F
7-14	16	128712	9.2	9.33	7.60	64536	62244	8.68	6.44	34.8
15-24	47	86382	9.8	10.41	8.83	36502	20527	9.39	8.90	5.5
25-34	3	9293	11.0	9.33	5.46	4588	4508	5.92	4.73	25.2
35-44	3	1941	6.9	6.90	7.10	591	546	7.83	5.45	43.7
45-54	7	18645	6.7	5.91	4.23	8517	8486	4.45	3.61	23.3
55-64	1	4950	5.4	5.40	5.40	2431	2519	5.70	5.00	14.0
65-74	1	497	3.2	3.20	3.20	-	-	-	-	-
75+	-	-	-	-	-	-	-	-	-	-

47

Table 15: Incidence of left-handedness in relation to geographical region of study.

Continent	Numbe r of studies	Number of subjects	Median	Mean	Overall incidence	Males	Females	Overall incidence: Males	Overall incidence: Females	100(M-F) -------- F
North America	45	112531	9.1	9.49	8.52	51545	36095	8.95	7.48	19.7
South America	2	1789	10.2	10.20	11.23	-	-	-	-	-
Europe	36	133401	8.9	9.13	6.71	61748	60767	7.51	5.50	36.5
Asia	8	30234	4.4	6.43	9.41	13035	12140	11.24	9.61	17.0
Australasia/ Pacific	6	6142	10.5	10.10	8.16	2138	2413	9.82	8.70	12.9
Africa	3	568	9.	7.73	7.57	-	-	-	-	-

48

Table 16. Degree of handedness in 2028 applicants to medical school (McManus, 1986, unpublished). Applicants were asked to state the hand used for writing on a five-point scale.

Classification	Males	Females	Chi-square
Always Right	968 (87.5%)	774 (83.9%)	
Usually Right	15 (1.4%)	47 (5.1%)	
Either	3 (0.3%)	3 (0.3%)	
Usually Left	6 (0.5%)	9 (1.0%)	
Always Left	114 (10.3%)	89 (9.7%)	
Total	1106	922	
pWR	0.015	0.057	
pWL	0.050	0.092	
pW	0.022	0.064	22.91, p<.001
pL	0.111	0.110	0.014, p=.905

49

Figure 1: Shows the overall incidence of left-handedness reported in 100 study populations, according to the criterion used for defining left-handedness. It should be noted that the 15 studies using a Right-Mixed-Left classification are entered into the figure twice (using different shading), once for an incidence of left-handedness of L/(R+M+L) and once for an incidence calculated as (L+M)/(R+M+L).

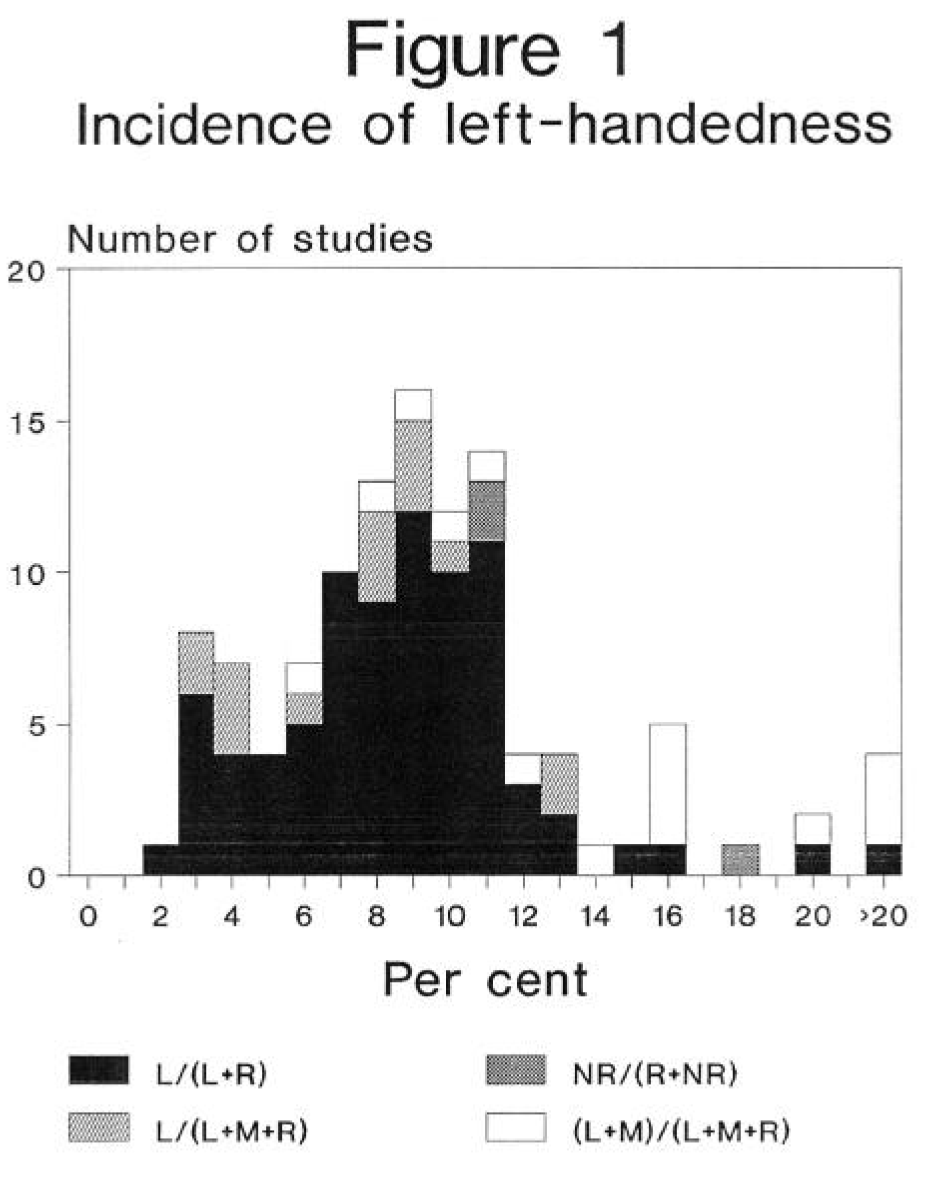

Figure 2: Shows the difference in incidence of handedness in male and females for 62 study populations. The percentage excess of left-handedness in males is calculated as 100*(M-F)/F.

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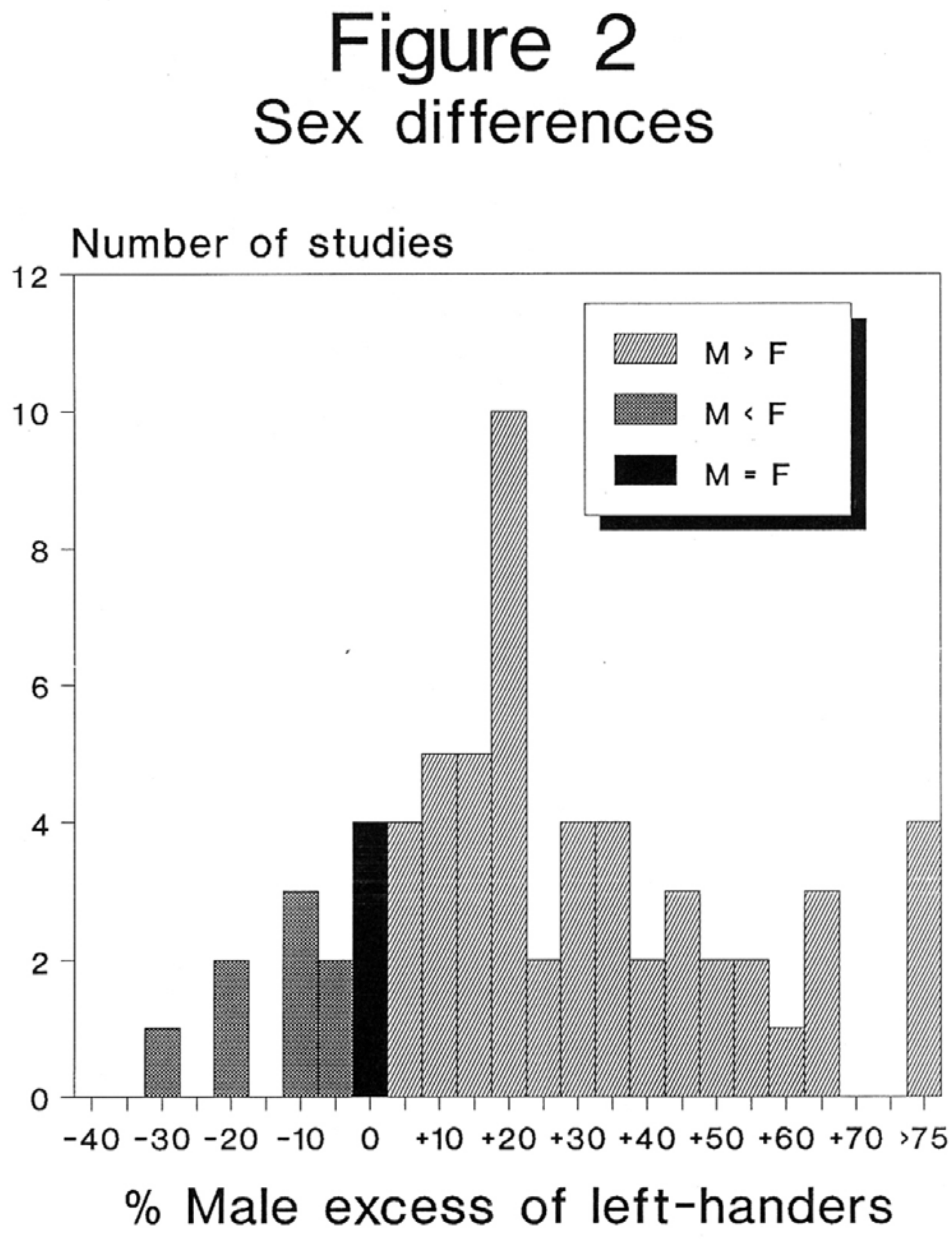

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65