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THE FACTOR STRUCTURE OF HUMAN HANDEDNESS:
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By

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ABSTRACT

THE FACTOR STRUCTURE OF HUMAN HANDEDNESS:
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By

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The present study was designed to assess the factor structure of handedness and, by this means, to better understand variations in handedness phenotype.

Four questionnaires (Personal Data Questionnaire, a 71-item Lateral Preference Questionnaire, Hand Preference Change Questionnaire, and Family Handedness Questionnaire) and one performance test (Dot-Filling Test) were administered to 502 American college students (439 right-handers, 61 left-handers, and 2 unclassified subjects based on self-classification). A short-form of the Lateral Preference Questionnaire also was sent to the students' parents to estimate the presence or absence of familial sinistrality and also to check the reliability of information provided by the students themselves on the Family Handedness Questionnaire.

Preliminary analysis (*a priori* cluster analysis, exploratory factor analysis, and blind confirmatory factor analysis) of the responses to the Lateral Preference Questionnaire, followed by confirmatory factor analysis, revealed 9 primary handedness factors and 3 other laterality factors (footedness, earedness, and eyedness). Hierarchical factor analysis applied to the correlations between primary factors yielded 3 second-order handedness factors and 1 other laterality factor, which were named "very skilled" (consisting of writing and drawing), "skilled" (e.g., use scissors, throw ball), "less skilled" (e.g., pick up paperclip, carry heavy suitcase, unscrew tight jar cap) and "other laterality." At the primary factor level, handedness thus appears to be multifactorial. The primary factors, however, were highly correlated, as were the second-order handedness factors, and were

consistent with the assumption of a one general handedness factor model. In sum, the factor structure of human handedness has a three level hierarchy: 9 primary factors, 3 second-order factors, and 1 general handedness factor.

The findings also showed that although a factor emerged for each modality at the level of primary factor analysis, a one-factor model perfectly fitted the pattern of correlations between modalities. This result thus suggests that a general laterality factor underlies all lateral preferences, but to different degrees for different modalities.

Based on the primary factor analysis, comparisons also were made between right-handers vs. left-handers, males vs. females, subjects with and without familial sinistrality, subjects reporting hand-change vs. those reporting no-change, and hand preference vs. hand performance.

To the memory of my father

삼가 아버님 영전에 이 논문을 바칩니다.

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INTRODUCTION

In human neuropsychology, there has long been interest in lateral cerebral specialization, or the functional asymmetrical organization of the cerebral hemispheres. Among neuropsychologists interested in this phenomenon, many have focused on handedness, or manual specialization, since this is probably the most salient manifestation of asymmetry. Despite many years of research, however, researchers still do not agree as to the precise nature of manual specialization (Bradshaw & Nettleton, 1981).

Research on handedness can be divided into at least three areas (Salmaso & Longoni, 1985). One area focuses on the relationship between handedness and cerebral organization for motor and cognitive functions in normal populations. Approximately 90% of human beings are right-handed (Annett, 1972; Hardyck & Petrinovich, 1977). In these individuals, control for handedness, in the sense of manual praxis, along with speech functions, is lateralized to the left hemisphere (Kimura, 1977). The fact that in right-handers, both manual and speech function are lateralized to the left hemisphere is generally considered to be central to an understanding of left hemisphere specialization in humans. However, the observation that right- and left-handers show different patterns of cerebral organization (Hécaen & Sauguet, 1971) has aroused considerable interest in the neuropsychology of left-handedness (e.g., Annett, 1978; Benton, Meyers, & Polder, 1962; Segalowitz & Bryden, 1983).

Another research area focuses on the cognition, personality, and other correlates of hand preference, for example, on the question whether, in comparison to right-handers, left-handers are poorer at spatial tasks (Lewis & Harris, 1990), at greater risk for reading, speech and/or language disorders (Homzie & Lindsay, 1984: Webster & Poulos, 1987), or more susceptible to auto-immune disorders (e.g., Geschwind & Behan, 1982; Geschwind & Galaburda, 1985; Searleman & Fugagli, 1987).

The third area focuses on cross-cultural studies of hand preference, which aim to better understand the respective roles of biological and environmental (cultural) influences on handedness.

Despite their different emphases, researchers in each of these areas have one common requirement - to determine the handedness of their subjects. Much attention therefore has been devoted to the question, how to make this determination? Several means are available, including direct observation of hand preference (Clark, 1957; Warren, Abplanalp, & Warren, 1967), binary categorization by writing hand (McManus, 1985), the administration of a handedness questionnaire (e.g., Oldfield, 1971; Provins, Milner, & Kerr, 1982) and measurement of hand skill, or performance (Annett, 1970b; Benton et al., 1962). Although Annett (1970b), who favors using performance rather than preference measures, argues that relative skill of the two hands is the major determinant of hand preference, the more popular method in neuropsychological research is the hand preference measure.

Among those who favor the hand preference measure, there also are differences in the decision rule for classification of handedness. Some regard "writing hand" to be the best single measure (e.g., McManus, 1985; White & Ashton, 1976) because it is the best predictor of a total laterality score. Others (e.g., Beukelaar & Kroonenberg, 1983; Payne, 1987) argue that because writing hand is often affected by social pressure and training, it is not a good indicator of overall handedness, especially for left-handers, who are more likely to have been discouraged (either overtly or tacitly) from writing with the left hand. The writing-hand measure also has been criticized as too gross to capture the range of lateral preference observed among non-right-handers

(Connolly & Bishop. 1992; Oldfield, 1971). Therefore, some researchers (e.g., Bryden, 1977; Coren & Porac, 1978; Oldfield, 1971; Richardson, 1978) stress the need for a simple, reliable description of handedness based on a small number of additional measures. Finally, research over the past few decades has disclosed that the relationship between handedness and cerebral lateralization for manual praxis and cognitive functions, once thought to be simple, is actually very complex (see Harris, 1991a, 1992a, for reviews). This has convinced some researchers (e.g., Healey, Liederman, & Geschwind, 1986; Provins et al., 1982; Steenhuis & Bryden, 1989) that a large number of diverse activities should be sampled in order to describe the concept of "handedness" adequately. Researchers disagree, however, about what kinds of behavior should be sampled. Although the particular items may have large effects on the laterality quotients obtained, the choice of items is usually arbitrary. Before theories about mechanism can be addressed, one must know what range of phenomena has to be accounted for. Therefore, the more basic questions about the phenotypic expression of handedness needs more attention: How is handedness expressed in the individual case?

An Overview of Factor Analytic Studies of Handedness and Other Lateral Preferences

Despite repeated attempts by a legion of researchers, there is still no agreement on basic questions about handedness phenotype. For example, on handedness questionnaires, there invariably are some individuals who do not report a clear hand preference across acts so that when we examine their preferences across a number of actions, we find a number of combinations of right-hand, left-hand, and either-hand responses. How can we make sense of such diverse combinations? One major strategy taken toward achieving a solution to this measurement problem has involved the use of factor analysis. Several researchers have measured handedness with multivariate instruments and have factor-analyzed the inevitable "messy" responses in hopes of identifying the underlying dimensions of handedness and thereby providing a more consistent and theoretically defensible set of rules for categorization of handedness groups.

Factor analysis is a statistical technique for "the resolution of a set of variables in terms of a small number of hypothetical variables, called factors" (Jöreskog, 1979, p. 5). In other words, it is a correlational procedure for analyzing scores on many separate test items in terms of a small number of factors. Although the models and methods of factor analysis are statistical in nature, factor analysis has been developed mainly by psychologists for the purpose of creating mathematical models for the exploration of psychological theories of human behavior. It first came into wide use for examining relationships among mental test items in order to identify the underlying components of intelligence. A brief review of the history of factor-analytic studies of intelligence will be useful as an introduction to the use of factor analysis in the study of handedness.

With factor analysis, Spearman (1927) found that all of the mental test items he examined were intercorrelated to a greater or lesser degree. On this basis, Spearman proposed that intelligence was composed of two factors - a general factor ("g") and a specific factor. Guilford (1985) came to the radically different conclusion that intelligence is multidimensional and that an adequate description of intelligence required nothing less than a complex, three-dimensional model, generating a total of 150 possible separate ability factors. Thurstone (1938) likewise viewed intelligence as multidimensional, although he proposed only 7 distinct primary mental abilities. Upon finding that these 7 abilities correlated moderately with one another, Thurstone proposed a hierarchical theory of intelligence which included "g" as well as second-order group factors fewer in number than the seven primary factors, which led him to propose a hierarchical model of intelligence. Cattell (1963) likewise recognized the "g" of intelligence, and, in addition, proposed two "group factors" (crystallized and fluid intelligence).

As in the studies of intelligence, the putative dimensions of handedness have been sought through factor analysis of questionnaire data. Like the studies of intelligence, the results also have been inconsistent. Some researchers have found only one major factor, meaning that the correlations between items in handedness questionnaires can be accounted for by only one substantial factor. Others have found several factors, suggesting that handedness is multifactorial.

Although research on lateral preference has focused on handedness, a few researchers have extended the analysis to include footedness, eyedness, and earedness. On the premise that a single, fundamental physiological factor leads to the formation of lateral preference, some researchers (e.g., Orton, 1937) have argued that all aspects of lateral preference should be aligned on the same side of the body. This position presumes the existence of a single direction factor and implies that a single mechanism influences the direction of handedness along with all other expressions of lateral preference. This expectation is borne out in a general way, since most people are likely to use the same-side hand, foot, eye, or ear across a variety of tasks. Recent evidence (e.g., Beaumont & Rugg, 1978; Dean, 1978b), however, indicates that the actual patterns of lateral preference often are more complex. To resolve this issue, several investigators have turned to factor analysis. For example, Porac, Coren, Steiger, and Duncan (1980) gave subjects ranging in age from 10 to 75 years a self-report inventory consisting of 13 items (4 items for handedness and 3 items for foot, eye, and ear preference, respectively). Their results revealed three distinct factors: a limb preference factor, which included both handedness and footedness; an eye preference factor; and an ear preference factor. These results thus suggest that lateral preference is multifactorial. Dean (1982) came to a similar conclusion based on a 49-item questionnaire, although, whereas Porac et al.'s analysis yielded only one handedness factor, Dean's analysis yielded three separate factors -- a general handedness factor; a factor for visually guided fine motor activities involving the arms and hands; and a factor for activities requiring hand strength. Dean also found separate factors for eye preference, ear preference, and foot preference. These inconsistencies across studies indicate that in order to understand lateral preference, we must study not only the factor structure of handedness itself but also how handedness is related to other expressions of lateral preference in the factor structure.

Is Handedness Unifactorial?

Apart from the question whether or not a single factor can account for all expressions of lateral preference (hand, ear, eye, and foot), researchers disagree whether a single factor can explain even hand preference itself, as Dean's study (1982) has already suggested. Many researchers have concluded that handedness is unifactorial. For example, White and Ashton (1976), using a modification of Oldfield's (1971) Edinburgh Handedness Inventory (EHI), found two factors, a handedness factor and a minor factor, which they decided was an artifact caused by the wording of certain items. Bryden (1977) used both Crovitz and Zener's (1962) and Oldfield's (1971) inventories and found a primary handedness factor consisting of the more skilled behaviors like writing, drawing, throwing a ball, holding a tennis racket, or holding a toothbrush. Bryden also found two minor factors that included bimanual behaviors (e.g., sweeping with a broom, holding the box-lid when opening a box) and holding behaviors (e.g., holding a dish while wiping it). He suggested, however, that because such activities are performed relatively infrequently or because the questions often require reversed responses (where the preferred hand is the nondominant hand), subjects must consider their responses carefully and, therefore, might not always answer correctly. Richardson (1978) also found that all of his 8 handedness items (writing, throwing, scissors, racket, toothbrush, striking a match, hammering, and threading a needle) were loaded on a single factor.

The questionnaire perhaps used most often in studies of handedness is the aforementioned Edinburgh Handedness Inventory (EHI). In its original form (Oldfield, 1971), the EHI consisted of 20 items measuring common unimanual and bimanual activities. In its current form, it has been reduced to 10 items (writing, drawing, throwing, scissors, toothbrush, knife [without fork], spoon, broom, striking match, and opening a box-lid) from the original set of 20. The 10-item EHI has been frequently factor-analyzed with less than totally consistent results from study to study. For example, Williams (1986), like several others, obtained a single "handedness" factor, but his results showed that "box-lid" and "broom" were less valuable indicators than the other items, among which "scissors" was the least highly loaded. McFarland and Anderson (1980) also examined the factor stability of the EHI. Although the handedness factor was very stable across both age and sex, "scissors" was relatively unstable in relation to the handedness factor, and "knife," "broom," and "box-lid" did not load well on the handedness factor. Their results were also supported by Provins et al. (1982). Raczkowski, Kalat, and Nebes (1974) also found that of 23 different items selected from the EHI and from Hull's (1936) inventory, the least agreement between a handedness questionnaire and a performance test was for the item "broom." This result supports Bryden's (1977) suspicions about bimanual behaviors. Plato, Fox, and Garruto (1984) had subjects perform 10 tasks involving 5 different functions and found that hand preference for two-hand tasks requiring whole body movement (holding a bat, putting a golf ball) was the most discordant from hand preference for the other 4 kinds of function, namely, single hand function (writing, hammering), single hand fine manipulation with minor assistance from subordinate hand (picking-up and pinning pins on a cushion), single hand fine manipulation with significant cooperation from subordinate hand for holding (cutting with scissors, lighting a match), and single hand function with whole body movement (pitching a baseball, serving tennis ball). Plato et al., like other unifactorialists, argue that two-hand tasks requiring whole body movement might provide misleading information about hand preference.

In summary, factor analyses of data from short questionnaires, usually the EHI, typically show that handedness is unifactorial for highly practiced unimanual activities, but they also suggest another factor associated with two-handed, or bimanual, tasks such as "broom" and "box-lid." However, researchers have not concluded that hand preference for these bimanual tasks constitutes another dimension of handedness. Instead, they have suggested that the data for these tasks are ambiguous either because the tasks themselves are less common, or that the questions require too much thought on the part of respondents (Bryden, 1977; White & Ashton, 1976). On the chance that these items therefore might yield misleading information, some researchers (e.g., Bryden, 1977; Raczkowski et al., 1974) have recommended excluding them from handedness questionnaires. According to the argument of the "unifactorialists," highly practiced unimanual tasks are closer than bimanual tasks to the "essence" of handedness.

Is Handedness Multifactorial?

Although Annett (1970a) concluded that hand preference could be characterized as a continuous variable with a single dimension, she delineated 8 preference classes of handedness by an association analysis[1] (Annett, 1985, pp. 199-203) of responses to her 12-item handedness questionnaire.

Dean (1982), using his own 49-item Lateral Preference Schedule (Dean, 1978a), found 3 handedness factors with 3 other lateral preference factors: (1) general handedness factor (e.g., writing a name, drawing a circle, eating with a fork, throwing a ball, hammering a nail); (2) visually guided fine motor activities involving arms and hands (e.g., raising a hand in school, petting a dog, holding a glass, picking up a penny, turning on a light); (3) eye preference (e.g., looking into a microscope, aiming a camera); (4) ear preference (e.g., putting one's ear against a wall to listen a strange sound, wearing a radio earphone); (5) activities requiring hand strength (e.g., opening a can of soda, holding a heavy object); (6) foot preference (e.g., hopping on, standing on longer). Unlike Porac et al. (1980), who used a 4-item handedness questionnaire along with a foot, eye, and ear preference inventory and found a single handedness factor, Dean found 3 separate factors (Factors 1, 2, and 5) related to handedness.

Beukelaar and Kroonenberg (1983) considered hand preference to be a naturally dichotomous trait rather than one lying along a single continuum. They administered a 51-item questionnaire to a large population of right-handed (n=518) and left-handed subjects (n=412) and used the proportions of persons performing each item with the <u>non-preferred</u> hand as data for the analysis. Their results for left-handers showed groupings of items that they characterized in terms of the muscle groups and joints presumably involved in performing the tasks: (1)

[1] Association analysis is a statistical method to "identify ways of making meaningful distinctions between individuals on the basis of patterns of hand preference" (Annett, 1985, p. 199). As in factor analysis, the correlation coefficients are calculated for all possible pairs of items in handedness questionnaires. Then, the correlations for each item are summed to discover which item is the most highly correlated with all others. The most highly correlated item is then used to divide subjects into those who perform the items with their right hand and those who perform it with their left hand. Within each subgroup, the calculations are repeated to find the items most highly correlated with all other items in the subgroup, and further subdivisions are made.

turning of the wrist (e.g., corkscrew, pouring water); (2) a stiff wrist, not requiring specific movement of individual fingers (e.g., light-switch, pressing pins); (3) ballistic, whole arm movement from the shoulder joint (e.g., throwing a ball, hitting someone); (4) delicate finger movements for tasks that typically are open to influence by social pressure or etiquette (e.g., writing, drawing, eating soup); (5) bimanual movement involving turning the spine and using the back muscle while using stick-like equipment (e.g., rake, broom); (6) and (7) moving the elbow, although the movement is ill-defined (e.g., cutting with scissors, slicing bread). For right-handers, Beukelaar and Kroonenberg could not include many items because of the extreme skewness of the distribution of scores. Therefore, the results for the right-handers were vague, although there were indications that the structure was the same. Beukelaar and Kroonenberg's analysis within handedness groups eliminated variations in handedness and thus reduced the importance of their results in that it did not show the factor structure of handedness in general for the whole population. In any case, their cluster analysis results are questionable because they used item means instead of individual differences and because they used "ϕ/ϕ_{max}" as a correlation measure when, in fact, it is not a correlation measure.

Healey et al. (1986) also argued that handedness is multifactorial and suggested that one important dimension distinguishing between handedness factors was the musculature involved in performing the task. This idea came from observations that some apraxics or aphasics preserved proximal/axial movement systems but not distal/pyramidal systems (Boller & Green, 1972; Geschwind, 1975). Healey et al. therefore hypothesized that those pyramidal and axial neural systems that control different aspects of manual preference are independently lateralized. Using a 55-item questionnaire, they found different dimensions of hand preference related to distal/pyramidal and proximal/axial behaviors. Factor 1 was a "general handedness factor" consisting of such tasks as writing, drawing, and sewing. These are relatively fine motor movements and require continuous modification of a motor program as a consequence of the effects of the prior movement. Factor 2 included hand movements governed by a program that requires little modification once initiated (e.g., point, snap the fingers). Factor 3 included an axial or a whole body movement (e.g., swing a baseball bat, carry a suitcase, do a cartwheel) involving strength more than fine motor dexterity and not involving continuous modification of the movement once it is initiated. Factor 4 included some ballistic movements of the proximal and/or axial musculature (e.g., throw a dart, bowl). These movements require more precision so that a specific target is reached. Activities in Factor 1 and 2 are distal/pyramidal behaviors, whereas those in Factor 3 and 4 are proximal/axial behaviors. Healey et al. found that right-handers were far more consistent for Factors 1 and 4 than for Factors 2 and 3, whereas non-right handers were significantly more consistent for Factor 1 than for each of the other factors. The authors concluded that their results imply the existence of a control system governing strongly laterally biased movements that is qualitatively different or distinct from the system governing laterally unbiased movements. Their results are consistent with Provins et al.'s (1982) prediction that highly practiced and skilled movements like writing, drawing, and throwing a dart would be more strongly lateralized than activities that depend on manual strength. However, that so large a proportion of the variance was accounted for by Factor 1 (71.5%) while other factors accounted for only very small proportions (Factor 2: 3.9%, Factor 3: 2.4%, and Factor 3: 1.9%) raises questions about the importance and perhaps even the existence of other factors.

Steenhuis and Bryden (1989) argued that the amount of skill required to execute a task is one of several critical dimensions. Their suggestion was that hand preference for less skilled behaviors could be influenced by factors such as the strength required for an action and the position of an object in space. They gave college students a 60-item hand preference questionnaire and found 4 factors: (1) general handedness, consisting of skilled unimanual motor activities involving movement of either the distal or the proximal musculature or both (e.g., writing, throwing a ball, inserting a pin); (2) less skilled unimanual tasks involving "picking up small objects" (e.g., picking up a pin, picking up a book); (3) bimanual tasks (e.g., resting a baseball bat on the shoulder, swinging an axe over the shoulder); (4) less skilled unimanual tasks related to hand strength (e.g., picking up or carrying a suitcase or heavy object). Unlike Healey et al.'s (1986) results, their factor analysis showed that skilled activities that required proximal movements such as throwing a ball or a dart are loaded on the general handedness factor with other distal movements, a result that strongly supports Steenhuis and Bryden's (1989) argument that the amount of skill required to execute a task is a more critical dimension of handedness than the distal and proximal dimension. However, Steenhuis and Bryden also acknowledged that skill could not explain all of the resulting factors. Therefore, they suggested another separate dimension related to hand/arm strength, similar to Dean's (1982) hand strength factor.

In sum, factor analyses of data from long questionnaires consisting of diverse items show that handedness is multifactorial, although researchers do not agree among themselves as to the nature of the multifactorial structure. Their results, however, have certain common characteristics that make their multifactorial structure questionable. One is that in all the "multifactorialist" reports, a general handedness factor accounts for a large proportion of the variance whereas other, minor factors account for only very small proportion. The other is that multifactorialists have not paid attention to the correlations between the factors and the possibility that the shared specific factors are included among their multifactors. If the factors are highly correlated, researchers should examine the possibility that there is a hierarchy of factors, beginning with "a general factor" that includes the primary factors. A way to make this determination is to factor-analyze the correlations between the factors. That is, although multifactorialists have found several factors underlying handedness, they cannot rule out the possible existence of a second-order, unidimensional, general factor that includes their primary multifactors.

As should be evident from this review, the unifactor-multifactor issue remains unsettled, with some researchers arguing that handedness is unifactorial, and with others arguing that it is multifactorial, and with even the latter not agreeing among themselves about to the nature of the multifactorial structure. What do these disagreements and discrepant findings mean, and can they resolved? There are at least three possibilities. One is that the disagreements reflect certain misuses of the factor analysis method. Another is that they reflect differences in the composition of the samples, most prominantly in the percentage of left-handers, or perhaps in the social-ethnic background of the subjects (the latter a potential index of "dextral pressure" on hand use). Still another is that they reflect differences in the number and types of manual activities in the handedness questionnaires that have been used. In the following sections, we shall consider each of these possibilities in turn.

Problems Associated with Use of Factor Analysis

To understand how factor analysis can be misused, it will be helpful to begin with a review of the basic principles of the method.

Basic Concepts of Factor Analysis.[2]

The "1's in the diagonal" and the "communalities." When we study any behavior, including handedness, what we observe is only a finite

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[2] The account given in this and the following section is based on analyses provided in Hunter (1977, 1980, 1985, 1988).

sampling of all possible instances of that behavior, hand preference for, say, writing as one instance, for throwing as another instance, and so on. We assume that there are certain underlying factors that constitute the basis, or underpinnings, of those behaviors, for example, the degree of skill or strength required. This means that in order to find the underlying factors, we must gather data on a large and representative sample of observed behavioral variables. The relation between the observed variables and the underlying factors can be described by a multiple regression equation ($X_i = a_{i1}F_1 + a_{i2}F_2 + \ldots + a_{ik}F_k + e_i$)[3]. The underlying factors are either correlated or independent. If underlying factors are uncorrelated with each other, they account for all the correlations that exist between the observed variables. Thus the regression weights in the model are the correlations between factors and variables ($a_{ik} = r_{XiFk}$). The matrix of factor-variable correlation is called the factor structure matrix. In the observed correlation matrix, if $i \neq j$, then r_{ij} is the dot product of the ith and jth rows of the factor structure matrix ($r_{ij} = \sum a_{ik}a_{jk}$). If, however, $i=j$, then $r_{ij} = r_{ii} = 1$, whereas the dot product for the diagonal is $r_{ij} = \sum a_{ik}a_{jk} = \sum a_{ik}^2 < 1$. The dot product formula works only for the off-diagonal entries, not for the diagonal entries of the observed correlation matrix. According to this formula, new numbers for the case $i=j$ are generated, and these are called the "communalities" of the variable X_i. The communalities are not observed values but true variables. The communality of variable X_i is the sum of squared correlations between X_i and the factors F_1, F_2, ... , F_k. In other words, it is the proportion of variance in X_i that is accounted for by the factors. The matrix whose diagonal entries (i.e., the 1's) of the correlation matrix are replaced by the corresponding communalities is called the "reduced correlation matrix." For 1's in the diagonal, each

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[3] The observed variables X_i are predicted using this equation, where the F's are the underlying factors, the a_{ik} are the regression weights, and the e_i are the errors.

factor is an exact linear combination of the <u>observed variables</u>. A factor analysis with 1's in the diagonal therefore ignores error of measurement. This means that correlations between factors will be artifactually low because of uncorrected error of measurement. For communalities in the diagonal, each communality will be the reliability of the corresponding variable and each factor will be a linear combination of <u>true scores</u>, with the resulting factors reflecting measured constructs that underlie each factor.

The principal components. The "principal components" (Hotelling, 1933) are factors that account for the maximum possible variance. When 1's in the diagonal are used, the principal components can be defined as follows. The first principal component is the linear combination of the observed variables that account for as much variance as possible. The second principal component is also the linear combination of the observed variables that increases the sums of squared multiple correlations for the two factors by the maximum amount. The second principal component is uncorrelated with the first principal component. The K^{th} principal component is the linear combination of the observed variables that adds the maximum amount possible to the sum of squared multiple correlations of the observed variables onto the K principal components. The K^{th} principal component is uncorrelated with the first K-1 principal components. If the communalities in the diagonal are used, all principal components are linear combinations of true scores rather than observed scores. The number of principal components is equal to the number of variables because none of the variables can be perfectly predicted from the others. There is no arbitrary answer to the question of how many principal components should be retained. It depends on how much of the variance the investigator wants to account for.

Rotation. Whether with 1's in the diagonal or with communalities, principal component factors are rarely substantively interpretable. For any given number of factors, there are many sets of factors that are mathematically equivalent[4] to the principal components but that are more interpretable. A new set of factors is defined as a linear combination of the old factors. The new factors then are called a "rotation" of the old factors. Several procedures for finding more meaningful rotations of principal components have been developed. If the new factors are uncorrelated, "orthogonal" rotation is performed. If the new factors are correlated with each other, an "oblique" rotation is performed. The most popular current method is VARIMAX (Kaiser, 1958), which is one of the orthogonal rotation procedures.

<u>Three Approaches to Factor Analysis</u>

There have been 3 main approaches to factor analysis: principal component analysis ("dust-bowl empiricism"), exploratory factor analysis (trait theoretic method), and confirmatory factor analysis (cluster analysis).

Principal component analysis. "Dust-bowl empiricists" (Hunter, 1980) want to keep factor analysis linked to purely mathematical computation rather than to content-oriented models. They criticize both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) as "subjective" and recommend principal component analysis as an "objective" alternative. Their usual practice is to use only the first few of the principal components as summary measures and to drop the rest according to eigenvalue. The problem, however, is that the principal components may not be substantively ordered according to the size of their eigenvalues. The importance of a principal component is a function of its substantive composition, not its eigenvalue. There are two factions among the dust-bowl empiricists. One faction defines a

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[4] According to the definition of equivalence, for the case of two old factors (F_1 and F_2) and two new factors (G_1 and G_2), if the G's can be computed from the F's and the F's can be computed from the G's, they are mathematically equivalent to each other. For example, if $F_1=.5G_1+.5G_2$ and $F_2=.5G_1-.5G_2$, then $G_1=F_1+F_2$ and $G_2=F_1-F_2$. G_1 and G_2 are linearly equivalent to F_1 and F_2. A new set of factors (G's) is defined as linear combinations of old factors (F's).

factor as a summary variable and therefore merely as a linear combination of the observed variables. It performs factor analysis with 1's in the diagonal in its correlation matrix and ignores error of measurement. The other faction is solely concerned with factor analysis as a mathematical procedure and is the same as the first faction except for the use of communalities.

Exploratory factor analysis (EFA). Trait theorists use the principal component method applied to the correlation matrix with communalities; their method therefore is called "principal axis analysis" rather than principal component analysis. Because principal axis factors have proven to be substantively meaningless, trait theorists rotate principal component factors to meaningful factors. There are two factions of trait theorists. One argues that factors must be orthogonal; the other argues that factors can be correlated. Exploratory factor analysis (EFA) makes no special assumption because it is independent of the empirical meaning of the data. If there is no theoretically given *a priori* measurement model, EFA suggests a provisional measurement model as a preliminary analysis. But the actual fit is poor for EFA in most studies (Hunter, 1980), and EFA as well as principal component analysis completely overlooks causal structure in the data.

Confirmatory factor analysis (CFA). CFA starts with an explicit measurement model. Variables are clustered so that the variables within each cluster (factor) are thought to measure the same construct. Each variable is assumed to be linearly related to the construct that it measures. If a cluster analysis is performed with communalities, the resulting factors are the hypothetically perfectly measured constructs that underlie each cluster. CFA tests the measurement model against data using methods that give considerable weight to item content and that directly examine internal consistency and parallelism.

a. Homogeneity of contents. Content is the most important criterion in assessing the quality of a factor. There should be good theoretical reasons to assume that all variables in a cluster measure the same underlying construct. In cluster analysis, it is not true that every item must be forced in somewhere, whereas this is required by definition in principal component analysis. Cluster analysis allows an item to be eliminated from the study or to be treated as a one item cluster if it does not fit the general pattern of the content of that study.

b. Internal consistency. Cluster analysis is intended to produce clusters whose variables (items) are measures of the same underlying trait. The intercorrelations among the items in each cluster are examined to detect items forming subclusters within a cluster.

c. Parallelism (external consistency). If all variables in a factor correlate similarly with variables outside the factor, we call those variables "parallel" or sometimes "externally consistent." Failure of parallelism can indicate a validity problem in an isolated measure. The variable would have to be parallel to all the other variables in that cluster. The comparison made is a visual inspection of the size and sign of variable-factor correlation coefficients. These several correlation criteria are much less likely to occur by chance. Thus parallelism has proved to be an excellent means of screening out bad items.

CFA improves on factor analysis in these three ways. Another difference between CFA and other forms of factor analysis lies in the further analysis of the data. After factors are obtained, a principal component analysis and EFA are terminated. Confirmatory factor analysts, however, turn to the analysis of the correlations between the factors. It is these correlations that are the actual target of most multivariate research. It is also the correlations between the clusters that reveal the causal processes.

CFA always give better estimates of population parameters than do principal components and rotation, that is EFA. The crucial thing is to use EFA as an exploratory technique to generate the hypotheses that produce a good CFA. CFA is theoretical, not subjective. The main difference between CFA and other forms of factor analysis is that CFA distinguishes between the measurement model, which assesses the extent to which various variables are indicators of certain traits and the causal model, which seeks to explain why the various traits are correlated as they are (Hunter, 1980).

Problems in Previous Factor-analytic Studies

With this overview, we can identify certain errors in previous factor-analytic studies of handedness. All of the prior investigations have used principal component analysis with 1's in the diagonal or EFA (in fact, principal component analysis without communalities and rotation). As already mentioned, principal component analysis produces substantively uninterpretable factors. If no theoretical *a priori* model is available, EFA might be a useful exploratory analysis to generate the hypothesis that leads to CFA (Hunter, 1985, 1988). The problem is that, with only a few exceptions (e.g., Bryden, 1977; Dean, 1982), the appropriate EFA method has not been used. Instead, a principal component analysis was performed with 1's instead of communalities in the diagonal of the correlation matrix. If 1's are used, each factor is a linear combination of the "observed" variables rather than the "true" variables, and correlations between factors are made artifactually low because of uncorrected error of measurement (Hunter, 1988). This also forces the number of factors to be more than 1. Therefore, the results of most factor analytic studies of handedness that used 1's in the diagonal should be reexamined with communalities.

A second problem associated with the use of factor analysis pertains to studies (e.g., Healey et al., 1986; Steenhuis & Bryden, 1989, 1990) that began with what seemed to be an implicit theoretical model and that used EFA. The problem is not with the use of EFA (even if the right EFA method was not used) but that the analyses stopped at that point. The VARIMAX rotation performed in previous studies is an orthogonal rotation and assumes that the factors are uncorrelated. However, to assume that handedness factors are uncorrelated with each other is too arbitrary. Therefore, the VARIMAX factors defined in EFA should be a starting point to get some preliminary idea about the factor structure. It should be followed by CFA producing correlated factors to find the underlying construct of handedness. In other words, Healey et al.'s (1986) distal/pyramidal versus proximal/axial dimensions and Steenhuis and Bryden's (1989) skilled versus less skilled dimensions should be validated by CFA with the examinations of the homogeneity of contents, internal consistency, external consistency (parallelism), and the correlations between factors.

A third problem is that multifactorialists have not examined the existence of shared specific factors and a general factor hierarchically including their primary factors. If two or more items have shared specific errors, these items will appear to be a cluster different from the other items and an EFA will tend to find as many factors as there are clusters (Hunter, 1984). A way to prevent this problem is to perform a "hierarchical (second-order) factor analysis." If the factors are highly correlated, then the question whether or not there is a general factor hierarchically including the primary factors should be examined by applying factor analysis to the correlations between the factors.

<u>Percentage of Left-Handers Among Subjects</u>

Some of the inconsistencies in the literature also might reflect uncontrolled differences in the samples. One not-negligible factor that influences the form of the handedness distribution obtained by questionnaire is the percentage of left-handers in the total sample (Healey et al., 1986; Steenhuis & Bryden, 1989).

Left-handers are known to be a very heterogeneous group. Although our understanding of left-handedness is still incomplete and uncertain, the consensus is that left-handers are less consistently left-handed than right-handers are right-handed (e.g., Annett, 1985; Benton et al., 1962; Healey et al., 1986; Humphrey, 1951). New evidence also suggests that left-handers are categorizable into 2 basic subgroups, consistent left-handers (CLH) and inconsistent left-handers (ILH). Peters (1990a) divided normal (i.e., nonpathological) left-handers into "consistent left-handers" (CLH), defined as those who consistently prefer the left hand for 7 out of 8 preference items including writing, and "inconsistent left-handers" (ILH), defined as those who prefer the right hand for 2 or more of the 8 items. He found that greater heterogeneity among left-handers for consistency of hand preference is associated with differences in an attentional mechanism. That is, CLHs show an attentional bias to the left during skilled bimanual activities, whereas ILHs show a bias to the right.

There also is ample evidence of handedness-related differences in cerebral organization for language and praxis. For example, with respect to lateralization of language functions, the evidence indicates that whereas nearly all (95% or more) right-handers have language specialization in the left hemisphere, left-handers show a more heterogeneous pattern. Although there is not yet complete agreement as to the nature of language specialization among left-handers, the consensus seems to be that about 65-70% have left hemisphere specialization, with the remainder divided roughly equally between right hemiphere specialization and bilateral specialization (Hécaen & Sauguet, 1971; Rasmussen & Milner, 1977; Segalowitz & Bryden, 1983).

The fact of greater heterogeneity among left-handers than among right-handers in handedness phenotype has led to disagreement about how subjects should be sampled in factor-analytic studies of handedness. Some investigators (e.g., Beukelaar & Kroonenberg, 1983) argue that right-handers and left-handers should be examined separately. Others (e.g., Healey et al., 1986) argue that a representative sample is not appropriate to describe both groups and that samples should include approximately equal numbers of each. Still others (e.g., Steenhuis & Bryden, 1989) argue that an analysis with equal numbers of right- and left-handers does not provide a good description of the characteristics of the population and that the description of handedness provided by a representative sample is more appropriate.

Even among studies using "representative" samples, a further problem is that different percentages of left-handers (ranging from 4.5% to 11%) have been included in the total sample. Although these differences are not very large, the possibility should not be overlooked that they reflect substantive differences in the left-handers themselves, with possible consequences for the results of these studies. The problem is further complicated when we try to compare studies across cultures. For example, left handers in conservative societies, those that restrict use of the left hand for certain actions including writing and eating, might be different from left-handers in liberal societies, that is, societies that do not impose such restrictions. The former left-handers perhaps can be called "stubborn" left-handers, in the sense used by Harris (1990b), who either do not wish to change or who wish to change but cannot. Harris (1990a) suggests that they might even comprise a distinct subgroup of left-handers, possibly neuropsychologically different from the others.

There may be no clear-cut way to resolve the question whether right- and left-handers should be examined together or separately. Ultimately, the decision might depend on the researcher's point of view about the nature of hand preference (see Beukelaar & Kroonenberg, 1983).

Social-Ethnic Background of Subjects

It is generally acknowledged that hand preference is influenced not only by biological factors but also by environmental factors such as special training, social conformity, and imitation. Most studies on handedness have been conducted in "liberal" countries that allow more-or-less free choice of hand use, although restrictions on left-hand use for certain acts such as handshake remain universal even in liberal countries (Harris, 1990b). To examine how much of this knowledge also applies to other countries and to what extent the genetic (biological) predilection for handedness direction and/or strength and consistency can be modified by environmental pressure, cross-cultural studies with subjects in "conservative" countries that still discourage or restrict left-hand use for certain acts are needed. Studies in several such countries have been conducted, including Colombia (Ardila, Ardila, Bryden, Ostrosky, Rosselli, & Steenhuis, 1989), Tanzania (Brain, 1977), Nigeria (Payne, 1981, 1987), Congo (Verhaegen & Ntumba, 1964), Sierra Leone, Hong Kong, and Australia (Dawson, 1972), Brazil (Brito, Brito, Paumagartten, & Lins, 1989), Germany (Peters, 1986), Italy (Salmaso & Longoni, 1983, 1985), Japan (Hatta & Nakatsuka, 1976; Komai & Fukuoka, 1934; Shimizu & Endo, 1983), and Taiwan (Teng, Lee, Yang, & Chang, 1976, 1979).

In all of these conservative countries, certain public acts, especially writing and eating, and, in some cases even the giving and accepting of gifts (Payne, 1987), are the prime targets. For writing, left-hand use was reported for less than 1% to 5-6% of the population. In these investigations, usually a single measure of writing hand or a short inventory of 3-20 items based on the Edinburgh Handedness Inventory (EHI) has been used. Studies in conservative countries generally support the position based on studies in liberal countries that handedness is unifactorial, although the researchers have not noticed or emphasized the factor structure of handedness because their main goal has been only to estimate the prevalence of left-handers. For example, Salmaso and Longoni (1985) used the original form of the EHI (20 items) and found that "writing" and "drawing" tend to dichotomize the population in the sense that most populations use the left or right hand, whereas preferences for "broom" and "rake" are distributed more evenly among right hand, either hand, and left hand. Brito et al.'s (1989) factor analysis of the EHI showed a single factor, on which "broom" and "box-lid" had the lowest loading. Teng et al. (1976), in their study of handedness in Taiwan, found that social pressure for right-hand writing and eating was effective on only these two skills with little indirect influence on hand use in other activities. Teng et al. (1979) also found that only 1% of their subjects reported exclusive left-hand use for "writing" and "eating," whereas nearly half of the subjects reported using either hand for "raising a hand," "reaching into a jar," and "opening a door." This finding suggests that the overall handedness distribution could have been affected by different selections of manual activities.

In sum, the results from conservative countries tend to indicate that handedness is unifactorial, at least for well-practiced unimanual skills. However, several studies of conservative countries also have shown that bimanual tasks (e.g., broom, rake, box-lid) or items strongly influenced by cultural pressure (e.g., writing, eating) have distinct characteristics, although researchers have not concluded that these items represent another dimension of handedness.

Among researchers who have studied handedness in conservative countries, Payne (1987) is the only one to administer a long self-report questionnaire involving a variety of activities (60 items) and to analyze the results by factor analysis. When Payne selected only those items with factor loadings of more than .60, as was done in studies of liberal countries (Healey et al., 1986; Steenhuis & Bryden, 1989), the result was a multifactorial structure very similar to that found in these other studies: (1) a general handedness factor pertaining to skilled unimanual activities (e.g., cutting with scissors, hammering a nail, throwing a spear); (2) familiar, unskilled, unimanual activities (e.g., knocking on door, waving good-bye, picking-up pins [.58]); (3) eating and interpersonal activities (e.g., eating with fingers, taking an object given to you, eating with a spoon); (4) bimanual activities (e.g., holding umbrella [.60], using a spade or shovel [.58], opening a box-lid [.56]); (5) bimanual activities requiring identification of the passive hand (e.g., holding a jar while unscrewing it, holding a dish while washing it). Two of Payne's (1987) results are especially interesting. One is the disclosure of an additional "cultural factor" (Factor 3) that was affected by social conformity pressure, which, according to Payne, suggests that the factor structure of handedness is influenced by societal characteristics as well as by the types of task items used. The other is that "writing" (.69) did not show the highest loading on the general handedness factor unlike most studies in "liberal" countries, whereas "scissors" (.87), which was identified as a less critical item in several previous studies (Coren & Porac, 1978; Richardson, 1978; Williams, 1986), now had the highest loading. Payne (1987) saw this result as showing that use of a long questionnaire can reveal the influence of social conformity pressure within a factor.

Number and Types of Manual Activities in Handedness Questionnaires

Still another possible contribution to inconsistencies in the literature is differences in the number and types of items comprising the handedness questionnaires. That is, studies sampling a small number of similar activities typically report a unifactorial structure (Bryden, 1977; Porac et al., 1980; Richardson, 1978; White & Ashton, 1976: Williams, 1986), whereas studies sampling a large number of diverse activities often report a multifactorial structure (Beukelaar &

Kroonenberg, 1983; Dean, 1982; Healey et al., 1986; Payne, 1987; Steenhuis & Bryden, 1987, 1989).

The smaller the number of activities used, the greater the likelihood of finding consistency for the preferred hand, which makes it easier to dichotomize people as right- or left-handed (Provins et al., 1982). Thus, Annett (1985, p.196), using a 12-item questionnaire, found that 161 (66.8%) of 241 adults reported a right-hand preference for all 12 activities, and 9 reported a complete left preference, whereas Provins et al. (1982), using a 75-item questionnaire, found that only 7 of 2,000 adults reported a complete right-hand preference and none reported a complete left-hand preference. Such differences have led to disagreements about the appropriate number and range of activities that should be considered. Some investigators, especially the unifactorialists (e.g., Bryden, 1977), object to the use of a large number of items on the grounds that less crucial or less relevant items may dilute the influence of the other items. Other investigators (e.g., Provins et al., 1982), however, argue that several of the questions in the Edinburgh Handedness Inventory (EHI) refer to activities that are highly practiced with one hand and probably rarely attempted with the other, so that using only a few highly selected items like those comprising the EHI will unjustifiably force people into one or the other of two dichotomous categories.

Several researchers (Beukelaar & Kroonenberg, 1983; Healey et al., 1986; Provins et al., 1982; Salmaso & Longoni, 1985; Steenhuis & Bryden, 1989) argue that the characterization of hand preference is influenced by the nature as well as by the number of questions. Salmaso and Longoni (1985) found that although the subjects' distribution into handedness groups on the basis of the original 20-item EHI did not differ significantly from that found for the 10-item version of the EHI, there was a significant difference between the distributions for the 10-item version of the EHI and a 10-item questionnaire consisting of items randomly chosen from the original 20-item EHI. Salmaso and Longoni therefore suggested that item type can be more crucial than item number in determining the shape of the distribution.

A related issue is whether the questionnaire should include highly practiced unimanual acts or activities strongly influenced by social pressure. Some researchers (e.g., Bradshaw & Nettleton, 1983; Bryden, 1982; Salmaso & Longoni, 1985) agree that only those items should be included that are the least subject to the effects of cultural pressure and practice. But Humphrey (1951) objected on the grounds that handedness reflects not only a person's natural inclination but also the influence of training and social influences. Recent factor-analytic approaches to hand preference using long questionnaires involving many kinds of manual activity offer some suggestions on this point. For example, Beukelaar and Kroonenberg (1983) found that most of the items influenced by social pressure or etiquette merge into one cluster, and Payne's (1987) factor analysis revealed a "cultural factor" consisting of items related to the preparation and consumption of food and to interpersonal interaction. These results provide important information about cultural influences on handedness and suggest that, rather than excluding highly practiced or "cultural" items, it may be more useful to examine the relationship between the "cultural" items and the others using a comprehensive questionnaire consisting of highly diverse items.

Characterization of Manual Activities Included in Handedness Questionnaires

As our review shows, researchers have included a highly diverse range of activities in their handedness questionnaires. According to their factor analyses, they have included behaviors that might be characterized as unimanual versus bimanual (e.g., Bryden, 1977; Plato et al., 1984; Williams, 1986), distal versus proximal (e.g., Healey et al., 1986), skilled versus less skilled (e.g., Steenhuis & Bryden, 1989, 1990), requiring or not requiring strength (e.g., Dean, 1982; Healey et al., 1986; Steenhuis & Bryden, 1989), and activities especially influenced by social pressure versus those not influenced (e.g., Payne, 1987). Although still other dimensions have been proposed, each researcher has emphasized one particular dimension over the others. Also, although many researchers have used long questionnaires, only a few questionnaires have been comprehensive, that is, have included many kinds of behavior. Strictly speaking, this means that the results of these different factor analyses therefore cannot be compared directly with one another. But taking all of these studies into consideration, we can propose that the following general categories of behavior should be included in order to obtain a comprehensive view of the nature of handedness and to identify its factor structure.

Skilled, Unimanual Behaviors

In many, if not all, studies, skilled, unimanual behaviors, such as writing, hammering, sewing, or throwing a dart or a ball, load on the primary handedness factor. Although most analyses consistently show one or more additional factors, they show that this primary factor explains the largest portion of variance by far (estimated from 41.6 to 71.5%). Therefore, this factor has been called the "general" handedness factor. Subjects report a strong preference to use one particular hand for the skilled, unimanual activities included in this general factor. These activities consist of proximal (axial) behaviors as well as distal behaviors, and they require the execution of a relatively complex sequence of motor behaviors. Steenhuis and Bryden (1989) suggested that neural mechanisms controlling the chaining, or sequential organization, of complex motor sequences such as articulation and praxis are more effective when one hemisphere is specialized for that control. Evidence shows that the left hemisphere normally assumes this role (Kimura, 1982; Kimura & Archibald, 1974), which suggests that the left hemisphere plays the leading role in well-practiced, skilled activities.

According to this analysis, one might expect well-practiced skilled acts of throwing (e.g., throwing a dart, a spear, and a ball, shooting a basketball) to be included in the general handedness factor. This has been so in most cases. However, Healey et al. (1986), who included a relatively large percentage of left-handers (31%) in their sample, and Beukelaar and Kroonenberg (1983), who examined left- and right-handers separately, found a separate factor for acts of throwing. One reason may have to do with the nature of the act. Consider the act of throwing a dart. By requiring quick, accurate limb movement coordinated with the "axial" movement of other parts of the body (torso, legs, and feet), and by emphasizing temporal precision in motor programming (Goodale, 1987), skilled throwing would be expected to draw on left-hemisphere systems. However, because skilled throwing also requires the processing of visuospatial information by the right hemisphere, this could make it different from other measures of lateral motor preference.

Throwing also differs from other manual acts by involving whole-body postural organization. In axial movements that involve the whole body, such as throwing a dart, bowling, or swinging a bat or axe, whole-body postural control is critical. One part of this control involves use of the feet. Footedness can be taken as indicating that specialization for postural control is in the contralateral hemisphere. Although there are many activities for which foot roles are complementary to hand roles, such as throwing a ball, foot preferences are not always related to hand preferences in a simple way (Peters, 1988). Although most right-handers are right-footed, about 50% of left-handers are also right-footed, using "kicking a ball" as the measure (Peters & Durding, 1979a). Searleman (1980) reported that on a dichotic listening test for the recognition of consonant-vowel syllables, 98% (39 of 40) of right-footed left-handers had a right ear (left hemisphere) advantage compared to only 67% (37 of 55) of left-footed left-handers.

MacNeilage, Studdert-Kennedy, and Lindblom (1988) noted that Peters' (1988) estimate that 50% of left-handers are right-footed approximates the percentage of left-handers estimated to have left hemisphere language, and they concluded from Peters' and Searleman's results that left-handers who are right-footed tend to have left hemisphere specialization for language and that their language control therefore is not dissociated from their control of whole-body posture. Chapman, Chapman, and Allen (1987) reported that left-handers with completely left-handed scores on a 13-item handedness scale (Raczkowski et al., 1974) are most likely to be left-footed.

As mentioned earlier, although there appear to be several different kinds of left-hander, over 90% of the normal human population may have language control and whole-body postural control in the same hemisphere. Therefore, in a representative population with the appropriately small percentage of left-handers, these subtypes of left-handers might not strongly influence the factor structure with respect to acts of throwing. However, if a disproportionately large number of left-handers are included, as in Healey et al. (1986), or if left- and right-handers' scores are analyzed separately, as in Beukelaar and Kroonenberg (1983), these subtypes of left-hander might be sufficient to bring out a separate factor for "proximal" throwing behaviors distinct from the unimanual skilled "distal" behaviors included as part of the general handedness factor. If so, it would support the emphasis placed by Healey et al (1986) on the distal/proximal dimension, even for skilled behaviors, at least where left-handers are concerned.

Less Skilled, Unimanual, Distal Behaviors

Less skilled, unimanual, distal behaviors can be divided into two groups. The first group consists of such less skilled, less complex distal unimanual behaviors as pointing, snapping fingers, or turning a light-switch. These behaviors require little modification once they have been initiated and show significantly less lateralization (Healey et al., 1986).

The second group consists of the acts of picking up small objects, such as a book or jar, or even smaller objects like a pin or paper clip from a flat surface. Research with primates (Lawrence & Kuypers, 1968) indicates that picking up a small object using thumb and forefinger is severely impaired following a lesion of the pyramidal tract. This suggests that these "picking up" acts involve control of the distal musculature and pyramidal tract like other activities included in the first group. Steenhuis and Bryden (1987) said that the act of reaching is determined by the location of the target item and the hand that is free at that moment. They found that although subjects report an increase in either-hand response for picking up objects, subjects still prefer their normally preferred hand for picking-up behaviors, in contrast to MacNeilage, Studdert-Kennedy, and Lindblom's (1987) argument that in primates the right hand is preferred for manipulating of objects and the left hand for grasping objects.

Although researchers generally have agreed that these two groups of behaviors -- less skilled/distal/unimanual actions and picking-up small objects -- have certain characteristics in common, such as being unimanual, distal, and less skilled, no researcher has found a single factor fully involving both activities of the two groups. Only Payne (1987) reported one factor (Factor 3) that involved items of both groups. Except for Steenhuis and Bryden (1989), however, researchers have not included a sufficient number of "picking-up object" items in their questionnaires. Steenhuis and Bryden (1989), who included many such items, found a "picking-up object factor" that consisted only of picking-up behaviors without other unimanual, distal, less skilled behaviors, although their questionnaire included several unimanual, distal, less skilled behavior items that belonged to one distinct factor in other studies (e.g., Healey et al., 1986). Therefore, whether these two groups of unimanual, distal, less skilled behaviors load on the same factor or whether "picking-up object" behaviors load on a distinct factor separately needs further study.

Proximal Behaviors

Even those researchers who favor a unifactorial model of handedness have found that questions about bimanual or unimanual proximal behaviors, such as use of a broom, baseball bat, axe, cartwheel, or carry a suitcase, do not load well on the general handedness factor (e.g., Bryden, 1977; McFarland & Anderson, 1980; Williams, 1986). Beukelaar and Kroonenberg (1983) obtained a separate cluster involving "tasks performed with both hands, involving turning of the spine and the use of back muscles, and that require stick-like equipment" (p. 41) such as rake, broom, spade, and bicycle pump. Plato et al. (1984) also indicated that hand preference for two-handed functions involving whole-body movement (bat and golf club) are not strongly related to other manual preferences. They proposed that the whole-body effort makes it easier for the potentially ambidextrous person to bat or putt with the "subordinate" hand. Healey et al. (1986) found a factor consisting of activities involving a proximal or a whole-body movement (e.g., baseball bat, suitcase, axe, cartwheel). They reported an increase in non-preferred hand use for these behaviors in both right- and left-handers. This finding is consistent with Provins et al.'s (1982) suggestion that activities that probably depend on manual strength, such as the hand used to carry a suitcase, or the hand put down first when doing a cartwheel, would be less strongly lateralized than skilled movements like throwing a dart, writing, and drawing.

Unlike other studies, Steenhuis and Bryden (1989) found separate factors for "bat/axe" and for "picking-up and carrying a heavy object (suitcase)." In their studies, two items, bat and axe, were strongly lateralized with many people reporting that they "always" did it a particular way, although both right- and left-handers showed a marked increase in nondominant hand use. Steenhuis and Bryden concluded that this factor relates specifically to the swinging of bats and axes.

The "picking-up and carrying a heavy object" factor in Steenhuis and Bryden (1989) showed a relatively low level of lateralized responses and an increase in "either" responses (40%). The authors therefore argued that there is a separate factor related to hand strength like Dean's (1982) hand strength factor. Unlike a general handedness factor whose items showed strongly lateralized responses, the existence of hand/arm strength as a separate factor that showed a low level of lateralized responses supports Porac and Coren's (1981, p. 13) result that the relationship between overall hand preference and performance measures of hand strength is generally poor.

Handedness and Sex, Familial Sinistrality, and Hand Preference Change

Previously, we reviewed the relationship between handedness and cerebral lateralization. Two major subject variables, sex and familial sinistrality (FS), have been thought to moderate this relationship. There have been many studies of the influence of these variables on the prevalence or strength of left- or right-handedness. Although they usually agree that both variables are related to handedness, they often do not agree about the nature of the relationship.

Another potential source of variability comes from the environment. We live in a right-handed world. There are numerous explicit and implicit pressures on left-handers to conform to the dextral norm even in "liberal" countries. How do such pressures affect handedness? Which individuals adjust or change their hand preferences as a result of these pressures? Which individuals do not? Do sex or FS also play a role here? With respect to the main question at issue, that of the factorial structure of handedness, factor analytic examinations of these variables could help to explicate their contribution to handedness and to provide valuable information about the nature of handedness. In the following sections, we take up each of these three variables -- sex, FS, and handedness change -- in turn.

Sex Differences

Many researchers have looked for sex differences in handedness. In some cases, significant differences have not been found (e.g., Annett, 1967; Ashton, 1982; Briggs & Nebes, 1975; Ellis, Ellis, & Marshall, 1988; Levander & Schalling, 1988; Porac, Coren, & Duncan, 1980; Salmaso & Longoni, 1983, 1985), but the greater number of studies have found differences indicating, in virtually all instances, that left handedness or mixed handedness is more common among males than females (e.g., Annett & Kilshaw, 1983; Annett & Turner, 1974; Brito, Brito, Paumagartten, & Lins, 1989; Chapman & Chapman, 1987; Hatta & Nakatsuka, 1976; Oldfield, 1971; Teng, Lee, Yang, & Chang, 1976, 1979; for a review, see Harris, 1990b). Even in these studies, however, the differences are quite small, at most indicating a 1-5% increase in the percentage of left-handedness in males.

The reasons for the sex differences have not been determined, but Harris (1990b) has suggested that two different kinds of influences may be at work. One is that the sex difference reflects physiological and biological differences between the sexes. These difference might take different forms. One possibility is that functional maturation of the left hemisphere occurs later in the male than in the female, a possibility consistent with evidence that male infants develop hand preference (at least right-hand preference) later than female infants (Archer, Campbell, & Segalowitz, 1988; Carlson & Harris, 1985). Alternatively, the differences might reflect the male's overall slower rate of physical development (Humphrey & Humphrey, 1987; Peters, 1986; Tanner, 1978) or even sex differences in the organization of neural mechanisms underlying praxis and speech in the left hemisphere (some evidence suggests that this organization is more diffuse in males than in females [Kimura, 1983]).

The other kind of influence possibly contributing to sex differences in the prevalence of left-handedness is social-cultural. The assumption here is that social pressure against left-hand use, like other general socialization pressures, is applied more strongly to women than to men (Barry, Bacon, & Child, 1957; Dawson, 1977), or that social pressure is applied equally to both sexes but that females are more susceptible to this pressures due either to their neurobiological advantage, their higher social compliance toward adults (Clark, 1957), or both (Maccoby & Jacklin, 1974).

Besides the direction of handedness (the prevalence of right- and left-handers), Porac and Coren (1981, p. 39) and Bryden (1977) have found sex differences in the degree (strength and consistency) of handedness. They reported that females are significantly more consistent than males in handedness pattern when only the strength, not the direction, of preference is considered. Oldfield (1971) found that the greater prevalence of left-handedness among males was a reflection of a greater number of left-handed males with scores distributed throughout the left-handed segment of the scale rather than a greater number of extremely left-handed males.

Like sex differences in the prevalence of left-handedness, sex differences in strength of handedness are not well understood. If lateral preferences reflect cerebral asymmetries, then sex differences in handedness presumably reflect a greater degree of bilateral cerebral organization, or weaker lateralization of function, in males than in females. However, some evidence, both from clinical and non-clinical studies, has suggested just the reverse, namely, stronger lateralization in males (see Harris, 1992a, for reviews). Kimura (1983) found that aphasia and apraxia in females occur more often from anterior than posterior damage to the left hemisphere, whereas in males, anterior and posterior injuries are implicated equally often. She suggested that there are sex differences in the organization of praxis and speech within the left hemisphere such that in females, speech and the associated oral and manual praxic functions are more dependent on the anterior than the posterior part of the left hemisphere, whereas in males, the two regions contribute more nearly equally or, if anything, show the reverse pattern.

From studies of the formation of paw preference in mice, Collins (1977, 1978) argued that genetic codes control the degree rather than the direction of expression of a functional asymmetry. According to Collins, female mice have a genetic complement associated with stronger expressions of lateral preferences, whereas male mice have a genetic complement associated with weaker preference. Extrapolating to human beings, it therefore could be predicted that natural right-handed females will be more right-handed and that natural left-handed females will be more left-handed, whereas both right- and left-handed males will show weaker, more mixed response patterns. Collins' predictions have been confirmed in studies of human handedness except in the case of female left-handers (Porac & Coren, 1981, p. 106). That is, whereas among right-handers, females are more strongly right sided than males, there are no sex differences among left-handers. Porac and Coren (1981, p. 107) argued that sex-related factors have their greatest influence in the determination of right-handedness at least in a right-biased world, whereas the determination of strong left-handedness in a right-biased world may involve other mechanisms unrelated to sex. This argument is very similar to Annett's (1985, p. 301) argument that the sex difference depends on factors inducing right-handedness because these factors are expressed more strongly in females than males.

The question then is, do all behaviors or only certain behaviors show the sex differences in handedness? Harris (1990b) suggested that the sex differences are stronger in the less socially controlled acts than in the more trained acts. His suggestion finds support in a study by Komai and Fukuoka (1934), which found large sex differences among Japanese school children for throwing a ball, striking a match, and using a scissors, but only small, even negligible, sex differences in writing, using chopsticks, and using a penknife. Supporting evidence also comes from a more recent study of American school children by McFarland and Anderson (1980), who found that of the 10 items on the EHI, only two items - "throwing" and "scissors" - showed significant sex differences, with males significantly more right-lateralized for throwing, and females significantly more right-lateralized for use of scissors. The implication is that throwing is a skill more likely to be practiced by males, and that use of scissors is more likely to be practiced by females.

Investigators who have studied the factor structure of handedness have included approximately equal numbers of males and females in their samples to control for any possible effects of sex on factor structure. Although many of these investigators have found sex differences in the number of left-handers, only a few have paid attention to these differences in describing the factor structure of handedness. Bryden (1977), an advocate of the unifactorial position (based on his finding a primary handedness factor and only two minor factors), concluded that the factor structure was approximately the same for males and females inasmuch as sex differences appeared only for the two minor factors, holding behaviors and bimanual behaviors, but not for the primary handedness factor. Dean (1982), an advocate of the multifactorial position, reported that the underlying factor structures were the same across sexes but that males were significantly more left-oriented in their patterns on all factors.

Many questions about the nature and magnitude of sex differences in handedness are still unsettled, such as whether the underlying factor structures are the same, as Bryden's (1977) and Dean's (1982) results indicate, or whether they are different; whether or not there are specific factors that show the sex differences in direction or degree of hand preference; whether or not certain behaviors within the factor show the sex differences, whereas other behaviors do not; and whether or not there are interactions between sex and handedness. Use of a comprehensive questionnaire with a more diverse set of items could help to answer these questions. It also could provide valuable information about the nature of sex differences in handedness.

Familial Sinistrality (FS)

As many researchers have pointed out (e.g., Annett, 1978, 1985; Ashton, 1982; McGee & Cozad, 1980), anecdotal evidence that handedness runs in families and the general recognition that the most pervasive and earliest cultural and environmental influences on the developing child come from the immediate family have led investigators to study handedness in family groups.

Adoption studies and twin studies have also been used to help differentiate environmental factors from genetic factors because these variables covary in biological families. However, because there are many nongenetic twin-related factors that increase the prevalence of sinistrality in both monozygotic and dizygotic pairs (Carter-Saltzman, 1980; Levy, 1976; Levy & Nagylaki, 1972) and because of difficulty in meeting the methodological requirement of adoption studies that contact with the step-parent must occur before the age at which most children establish hand preference, family studies have been the primary source of information about both genetic and environmental factors in the etiology of hand preference.

Generally, family studies assess either the prevalence of left-handedness among the relatives of the left-hander or the prevalence of left-handed offspring from different mating types (McGee & Cozad, 1980). The findings are mixed. Briggs and Nebes (1975) and Searleman, Tweedy, and Springer (1979) reported that FS was more common among left-handers than right-handers, whereas Spiegler and Yeni-Komshian (1983) found no differences (39% for right-handers versus 42% for left-handers).

McGee and Cozad (1980), following an analysis of major family studies (Chamberlain, 1928; Rife, 1940; Merrell, 1957; and Annett, 1973, 1978), found that the proportion of children showing a left-hand preference increases with the following mating types: both parents right-handed (RR), father left-handed and mother right-handed (LR), father right-handed and mother left-handed (RL), and both parents left-handed (LL). By contrast, Carter-Saltzman (1980) showed that for adopted children who were placed in their adoptive homes during the first year of life, the prevalence of non-right handedness did not vary systematically with parental handedness.

Many family studies (e.g., Annett, 1973, 1978; Ashton, 1982; Chamberlain, 1928; Falek, 1959; Rife, 1940) also have found, although the results have not always been statistically significant, that in families with a single nondextral parent, the prevalence of nondextrality in the offspring is higher when the nondextral parent is the mother. Other studies (Hicks & Kinsbourne, 1976; Levy, 1976; Merrell, 1957; Rife, 1940), however, have not found this "maternal effect." Leiber and Axelrod (1981) argued that the relationship between the mother's handedness and the child's handedness cannot be causal because the majority of left-handers have a right-handed mother and the majority of children of left-handed mothers are right-handed.

There also is evidence that the maternal effect is moderated by the sex of the child, although the direction of the effect is unclear. Annett (1973) and Chamberlain (1928) found that the maternal effect was more noticeable for daughters than for sons; McGee and Cozad (1980) did not find this effect. Spiegler and Yeni-Komshian (1983) reported that maternal left-handedness was associated with an increase in the prevalence of sinistrality for sons and daughters alike, whereas paternal left-handedness was related only to sons. Rife (1940), however, found a significant correlation only between fathers and daughters.

"Environmental" theories of handedness have proposed two different explanations of parental influence on handedness, although neither explanation is clearly supported by the data. One is that because the mother usually has the closer early relationship with the child, she influences the child's handedness more than the father does (Morgan & Corballis, 1978). The other is that the nondextral father exerts more pressure toward dextrality in his children because he is more aware of the occupational disadvantages of sinistrality than the nondextral mother. Therefore, the nondextral father is more likely to attempt to reverse his children's sinistrality, with successful attempts more likely to result in switched handedness rather than in small changes in the strength of handedness (Falek, 1959).

Besides parental sinistrality, Leiber and Axelrod (1981) found that the presence of nondextrality in siblings was consistently associated with large and statistically reliable increases in the prevalence of sinistrality and nondextrality.

FS and the direction and degree of handedness. Researchers (e.g., Annett, 1973; Falek, 1959; Levy & Nagylaki, 1972) interested in genetic or familial factors in handedness have relied on directional or sidedness measures of handedness. However, the prediction of individual left- versus right-handedness based on knowledge about the handedness of family members does not appear to be a successful approach. The most obvious difficulty arises in situation where both parents are left-handed (LL). Porac and Coren (1981, p. 73) synthesized the previous studies and reported that on average 60% of the offspring of left-handed parents (LL) are right-handed. The overall picture obtained from the family studies shows only weak evidence for the genetic transmission of handedness, although a maternal effect on handedness is found consistently.

These results have led several investigators (e.g., Bryden, 1979;

Porac & Coren, 1981) to suggest that the degree (strength and consistency) of handedness might be a better measure than the direction of handedness. Bryden (1979) found parent-offspring resemblances in the speed of tapping when he considered absolute scores regardless of direction of handedness, whereas the relationships for direction were minimal. Porac and Coren (1981, p. 87) found that whereas the measures based on the direction of handedness provided little suggestion of a familial component except for the maternal effect, the strength measures showed familial patterns of similarity for handedness. There were sibling as well as parent-offspring similarities in the degree of manifest handedness. These patterns could indicate a genetic component for strength of hand preference in support of the theoretical positions of Bryden (1979), Collins (1977), and Morgan (1977), who argue that genes encode the strength of asymmetry rather than the direction of preference.

The question of direction versus degree, however, remains unsettled. McKeever and Van Deventer (1977) examined the relationship between FS and strength of sinistrality in a student population using the Edinburgh Handedness Inventory and three manual tasks. They failed to find any relationship between FS and the degree of right-handedness in right-handers. Although FS+ left-handers showed a larger left-hand superiority than FS- left-handers on only one of the manual tasks, there was no evidence of a general relationship of degree of left-handedness to FS. Leiber and Axelrod (1981) pointed out the confounding between prevalence and degree of handedness in several studies (e.g., Hicks & Kinsbourne, 1976; Annett, 1967). Leiber and Axelrod analyzed both the prevalence of handedness types and the degree of handedness with the information provided by university faculty members and students. They found that familial sinistrality was associated with large increases in the prevalence of nondextrality but with very small changes in the degree of handedness. That is, the prevalence of nondextrality in

respondents was significantly higher when siblings are nondextral than when all relatives were dextral, and higher still when a parent, rather than a sibling, was nondextral. FS+ was associated with small reductions in degree of handedness in sinistrals as well as dextrals. Therefore, the issue about direction versus degree needs to be investigated further.

Assessment of FS. Some of the inconsistencies in the FS literature might be related to differences in how FS is measured (Harris, 1992a). The decision rule most investigations use for identification of FS requires at least one left-hander among immediate family members, regardless of family size. Some researchers (e.g., McKeever & Van Deventer, 1975) include left-handedness even in the extended family such as biologically related aunts and uncles. Bishop (1980) recognized the possibility of a systematic bias from the differences of family size and recommended matching groups of FS+ and FS- subjects on family size or rating FS only in terms of those relatives common to all individuals, namely parents and grandparents. As a method of taking family size into account, Spiegler and Yeni-Komshian (1983) transformed the number of left-handers per family into a percentage score. This is only a partial solution because small families that include left-handers would be more likely than large families to be classified in the higher FS categories. To study FS more comprehensively, Lieber and Axelrod (1981) examined five FS variables: parental handedness; sibling sinistrality; nondextral siblings (older versus younger); familial handedness (all dextral, nonright siblings only, nonright parents only, and nonright siblings and nonright parents); and familial sinistrality (at least one parent or sibling is nondextral).

The need for a more valid assessment of the handedness of subjects' relatives also has been recognized (Bryden, 1977). Although handedness of relatives has often been determined simply by asking the subjects whether relatives were left-handed without providing the subjects with any criteria for making this determination (Andrews, 1977), two criteria used in previous studies are to ask about writing hand (Annett, 1973) or about hand preference for "any" of several unimanual tasks (McGee & Cozad, 1980). It has been recognized that defining handedness by the writing hand underestimates the number of left-handers (e.g., Selzer, 1933). Dean (1978a) developed the maternal and paternal scale consisting of five items each that were the most frequently recalled parental tasks for undergraduate students.

In many studies of familial sinistrality, data were collected from the children rather than from the parents directly. Some researchers therefore have proposed that the frequently reported generation difference in part reflects inaccurate knowledge on the part of the respondent. That is, some bias toward reporting less left-handedness for parents may be built into data collected from high-school students (Porac & Coren, 1979a) or college students (Annett, 1979). Several findings (Annett, 1973, 1978; Ashton, 1982; Falek, 1959), however, argue against this interpretation. They showed that providing information for relatives does not necessarily bias the results. For example, Annett (1978) reported that the prevalence of left-handedness in parents was similar between the several subsamples in which some parents had personally completed questionnaires and others had been reported by their student children.

Many questions about the relationship between FS and handedness remain unanswered. With respect to the factor structure of handedness, a factor analytic approach would help answer the following questions: If handedness proves to be multifactorial, will specific factors be significantly correlated with FS? Are there specific factors that show the differences in direction versus degree of handedness between FS+ and FS-? If so, are there differences between right- and left-handers or between males and females? Answering these questions could help us better understand the relation between FS and handedness.

Hand Preference Change

There have been consistent reports (e.g., Annett, 1973, 1978; Chamberlain, 1928; Merrell, 1957; Rife, 1940) of systematic changes in the direction of hand preference across generations, consisting, in one study, of a mean increase in left-hand preference of about 4% in one generation, offspring over parents (McGee & Cozad, 1980). These generational changes can be explained if we suppose that hand preference remains sufficiently plastic that it can be affected by external influences such as a particular environment, culture, or form of socialization and personal motivation (McGee & Cozad, 1980; Porac & Coren, 1981).

Investigators interested in familial sinistrality as well as those interested in sex differences in handedness have been encouraged to consider the influence of environmental factors because the research findings do not yet provide compelling evidence for a simple genetic or biological explanation of either handedness itself or of sex differences in handedness. At one extreme, Ashton (1982) argued that 80-90% of the factors involved in the formation of the handedness phenotype is related to environmental influences. A theory to explain the predominance of right-handers in human populations is the "right-sided world hypothesis," which holds that social and physical environments have been established to favor right-handedness, and that there is continual overt and subtle pressure on left-handers to conform to this dextral norm. Although a few anecdotal accounts support this hypothesis (e.g., Carrothers, 1947), only a few studies have investigated these pressures directly. Falek (1959) found that early family pressures related to both socioeconomic status (SES) and parental hand preference influenced children's hand preference. Left-handed fathers who were laborers or blue-collar workers who might have experienced some discomfort and social pressure in their professional or occupational settings and knew the disadvantage of sinistrality were more likely to apply pressure against left-handed use in their children than the left-handed mothers, whereas right-handed parents remained indifferent to their children's handedness. Falek's results suggest that left-handed fathers' overt pressure would result in reversed hand preference among children showing a sinistral tendency rather than the production of small alterations in degree of handedness.

Cross cultural studies also suggest that differences in the prevalence of left-handedness among different cultural groups probably reflect attitudinal differences about left-hand use. Whereas liberal countries tolerate the presence of left-handedness, conservative countries impose a variety of pressures to shift individuals away from left-handedness (e.g., Dawson, 1977; Marrion, 1986; Payne, 1987; Salmaso & Longoni, 1985; Teng et al., 1979). This does not necessarily mean that there are no longer any pressures against left-hand in liberal countries. Even overt pressures have been reported (Porac et al., 1986). The question is, what form does this pressure take? How early and in what ways does it begin to work? How many and what kinds of left-handers change their hand preferences due to these pressure as a result?

Harris (1990b) suggested that although formal hand writing training begins when the child enters school, informal instruction can start much earlier when parents (or preschool teacher) place the crayon in the child's right hand or even in infancy through the infant's imitation of the parent's own hand use (Harkins, 1987, cited in Harris, 1990b). Early anecdotal reports also indicate that instruction in table manners may begin by placing the spoon closer to the child's right hand or into the right hand directly when the child is old enough to reach for food or to hold a spoon (Harris, 1990b). Fitzgerald and his colleagues (Fitzgerald, Harris, Barnes, Wang, Cornwell, Kamptner, Dagenbach, & Carlson, 1991) found that parents, regardless of their own handedness, exerted moderate pressure for right-hand use on their 9-month-old infants. Ashton (1982) suggested that early maternal training may be a major determinant in handedness formation. Leiber and Axelrod (1981) investigated hand preference change directly in 2257 university faculty and students. Of this group, 3.5% reported that they had "switched" their handedness in the past. Of this group, 60% changed from left to right, 27.5% declared themselves to have become ambidexters, and 12.5% changed from right to left. Of the subjects reporting a change, 58% said that they had been motivated by factors in their early family or school environment. Of those who changed, 67% reported that they had made the change by the age of 8, and 85% by the age of 15. The results also indicated that the prevalence of FS was virtually identical among the hand change (34%) and no change respondents (35%). For this reason, Leiber and Axelrod concluded that incidental intra-familial modeling or adaptation has only a minute effect on hand preference.

Porac, Coren, and Searleman (1986) reported similar results with a sample of students at a Canadian university, 11.2% of whom reported having experienced attempts to change their hand preferences, with 8.0% experiencing pressure to switch hand preference from left to right, and 3.2% from right to left. Of those reporting a change, 5.2% said that they underwent a complete left- to right-hand change, with the majority reporting that they experienced pressure to change handedness before 8 years of age (grade 3).

Porac, Rees, and Buller (1990), with a sample of university students and staff members, have identified some of the different circumstances under which a hand-use shift is initiated. In right-shifters (i.e., shifting to right-hand use), parents or teachers initiated the attempts before the early grade school years, using the method of switching an implement from one hand to the other, whereas left-shifters initiated the attempts themselves out of a spirit of personal experimentation or because of curiosity about their potential left-hand abilities. The change attempts in the left-shifters occurred in later childhood or early high school years. Most left-shifters said that they sought ambihandedness rather than a complete switch to the left hand.

Several studies have reported that any change in handedness by external pressure tends to be very circumscribed. Teng et al. (1976) found in a large sample of grade school and university students in Taiwan, where there is strong pressure against eating and writing with the left hand, that left-handers who switch to the right hand for eating and writing continue to use the left hand for other tasks such as striking a match, hammering a nail, or brushing teeth. Against this evidence of circumscribed effects, Tan (1983) compared the hand use of two generations of Australians and reported that although the largest differences were found for writing and drawing, other items, such as hammering, using a toothbrush, and holding a glass, also showed lower percentages of left-hand use in the older generation. This suggests that cultural pressures to conform to the dextral norm may be able to influence a wide variety of acts. To reconcile these two kinds of reports, as Harris (1990b) suggests, it is necessary not only to obtain more information about the actual timing and nature of training but also to analyze the similarity and difference between trained and untrained behaviors (Beukelaar & Kroonenberg, 1983) according to the level of social control (Annett, 1985), the dimension of skill required (Steenhuis & Bryden, 1989), and the dimension of strength required (Dean, 1982; Steenhuis & Bryden, 1989).

The question of the completeness of hand change can be raised with respect to the strength and consistency as well as the direction of handedness. Leiber and Axelrod (1981) reported that intentional reversals of handedness result in decreased strength and consistency of hand usage, regardless of the direction of change. They found far fewer dextrals and far more ambilaterals among the hand-change than among the no-change subjects. Moreover, respondents who had switched either to right- or left-handedness were less strongly and less consistently right- or left-handed than their no-change counterparts. Leiber and Axelrod suggested that this indicates definite biological limits on the influence of training on human handedness. Porac et al. (1990) also found that individuals who experienced pressure to change handedness were more ambihanded than no-shift controls. That is, the majority of the individuals who experienced pressure to change handedness were not successful in producing a change in handedness classification in the direction of the shift. Porac et al. argued that this ambihanded pattern can be explained by two ways. Either the shift attempts were only partially successful, with only some behaviors moving in the direction of the attempted switch, or these individuals were naturally ambihanded and it was this tendency that produced an interest in switching hands. Porac et al.'s results seem to favor the first explanation.

Although Porac et al. (1986) did not find any sex difference in the likelihood that an individual experienced pressure to change hand use or in the sex composition of the right-shift group versus the no-change group, they did find that females reported greater success in shifting their handedness than males. Porac et al. therefore concluded that females respond to pressures to change hand preference in ways different from males. Even so, a recent study of Porac et al. (1990) did not find a sex difference favoring females in the rate of success of right-shifters. The earlier results (Porac et al., 1986) also indicated that among females, parents were the most frequent agent of change, the writing hand was the most frequently targeted behavior, and the change was instituted most often in the preschool and early grade school years. Contrary to Falek's (1959) suggestion, proportionately more males whose families consisted totally of right-handers were in the right-shift group (84.2%) than in the no-change group (56%). For females and for the total sample, this familial handedness effect was not found.

In summary, many questions remained unanswered about the nature and limits of hand preference change. This is yet another domain of study of handedness to which factor analysis could make important contributions. For example, are there specific factors that show the differences of direction or strength in handedness between hand-change and no-change group? Factor analysis also could help to illuminate the relationship between sex, FS, and hand preference change: Recall the suggestion that some left-handers change to right-hand use, whereas others (so-called "stubborn" left-handers) do not (Harris, 1990b). Can sex or FS explain some of the differences between these two groups of left-handers in relation to the factor structure of handedness?

Hand Preference and Hand Performance

The idea of handedness implies the greater competence, accuracy, strength, and preponderant role of the dominant hand. Therefore, a method to measure the performance level attained by each hand on one or several motor task(s) requiring strength or skill (i.e., speed, accuracy) and to determine which hand achieves the better performance has also been used to identify the dominant hand. Annett (1976) argued that this proficiency measure leads to a more refined measure of handedness. Annett's view was that degree of hand preference is determined by the underlying continuous distribution of relative hand skill. Therefore, to quantify handedness, she recommended direct performance measures of relative proficiency rather than use of a preference inventory.

There has been a tendency to regard strength, skill, and preference as relatively interchangeable indicators of the dominant hand (Annett, 1985). Much evidence (e.g., Bradshaw & Nettleton, 1983; Porac & Coren, 1981; Provins & Cunliffe, 1972; Satz, Achenbach, & Fennel,

1967) shows that hand preference and hand performance are correlated with each other, but only weakly so. The poor concordance between hand preference and hand strength has been reported by many researchers (e.g., Annett, 1985; Provins & Cunliffe, 1972; Satz et al., 1967). For example, using grip strength as their measure, Provins and Cunliffe (1972) found that 35% of right-handers defined according to a preference measure, showed a stronger left-hand grip, while 75% of left-handers showed a stronger right-hand grip. Johnston, Galin, and Herron (1979) reported that the correlation between a dynamometer test for hand strength and preference inventories was only .31, although it was statistically significant.

Studies of the relationship between hand skill or dexterity and hand preference also have given inconsistent results. With a manual dexterity task requiring tweezer-manipulation of small objects, Benton and his colleagues (1962) found that 10% of self-declared right-handers were better at the task with their left hand, while 27% of left-handers were better with their right hand. This poor concordance between preference and skill was also found by Satz et al. (1967) and Provins and Cunliff (1972). Finlayson and Reitan (1976), however, found that measures of speed and dexterity correlated reasonably well with hand preference, whereas measures of strength and sensory sensitivity did not. Annett (1985) found an orderly linear relationship between the degree of hand preference and the degree of hand performance using tapping task data reported by Peters and Durding (1978) as well as her own data from her peg-moving task (Annett, 1970b; Annett & Turner, 1974). She therefore argued that hand preference and hand performance were related and that the relationship was highly reliable and systematic. Tapley and Bryden (1985) also reported that performance on a paper-and-pencil dot-filling task was highly correlated ($r = .75$) with the preference inventory.

Preference questionnaires typically yield a J-shaped distributions, with the percentage of individuals showing a right-hand preference typically falling in the 85-90 percent range, which means that 10 to 15 percent of adult population are left-handed (Annett, 1970a; Crovitz & Zener, 1962; Oldfield, 1971). Nevertheless, the distributions of scores (e.g., right-hander's performance minus left-hander's performance <R-L>) based on performance measures of handedness have showed approximately normal curves (Annett, 1972; Benton et al., 1962; Satz et al., 1967). There is no sign of a dip in the curve at zero to indicate a natural division between right-handers and left-handers. Recently, Bishop (1989) showed that a J-shaped distribution of preference scores can be derived directly from a normal distribution of proficiency scores. She also found significant correlations between preference scores and proficiency scores from a computer simulation (i.e., with a 5-item preference scale, the correlation was .70; with a 9-item scale, it was .72), which were closely similar to those obtained with real data on preference and proficiency. Bishop argued that the moderate correlation between measures indicated that hand preference and hand asymmetry in performance can be considered as two facets of the same phenomenon, although it cannot prove that hand preference is determined by relative proficiency.

Although some researchers (Benton et al., 1962; Peters & Durding, 1979) found that left-handers showed weaker lateralization than right-handers in performance tests as well as in preference tests, others (Borod, Caron, & Koff, 1984; Peters & Durding, 1978; Satz et al., 1967) have reported that the lateralization pattern for left-handers did not differ significantly from that for right-handers. Peters and Servos (1989) found that consistent left handers (CLHs), like right-handers, showed consistent and marked strength and skill differences between hands, whereas inconsistent left-handers (ILHs) were stronger with the right hand but tapped faster with the left hand, thus indicating a skill and strength dissociation. Peters and Servos argued that if distinctions between CLHs and ILHs are not based on performance studies, misleading statements about the nature of left-handers arise as they do in preference studies.

Although significant sex differences have been found with females showing greater lateralization for measures of performance (Annett, 1970, 1972, 1985; Tapley & Bryden, 1985), some researchers (e.g., Lake & Bryden, 1976; Levy & Gur, 1980; Inglis & Lawson, 1981) reported that right-handed females were less lateralized than males in performance tasks. Non-significant laterality differences between males and females in performance tasks also have been reported in other studies (Barnsley & Rabinovitch, 1970; Borod et al., 1984; McGlone, 1980; Peters & Durding, 1978, 1979b).

These inconsistent results in handedness and sex differences in performance as well as in the relationship between hand preference and performance may mean that the different hand performance measures are not measuring fundamentally the same skills. Low correlations among the various performance measures themselves have been reported. Porac and Coren (1981) reported only a 59% mean percentage agreement across 8 performance tasks. Fleischman (1972) and Barnsley and Rabinovitch (1970) found that hand performance measures are multidimensional in nature. They identified multifactors such as fine dexterity, manual dexterity, aiming, arm-hand steadiness, and reaction time. If, as these results suggest, different tests of hand performance measure different factors, the concordance between performance and preference would be task-specific.

These inconsistent results also may reflect each study's use of a different criterion for measuring hand preference, ranging from self-declaration of a preferred hand (Benton et al. 1962) to a 31-item inventory covering a relatively wide range of activities (Provins & Cunliffe, 1972). Many researchers (e.g., Annett & Kilshaw, 1983; Borod et al, 1984; Peters & Durding, 1979b; Tapley & Bryden, 1985) used a short inventory consisting of 7-12 items pertaining to only the more skilled behaviors like writing, throwing a ball, using scissors, and hammering a nail. If the performance task used in a study required skilled behaviors similar to the preference measures used in the same study, it seems more likely that hand preference and hand performance would be highly correlated. However, if the performance and preference items were very different (for example, a performance measure of hand strength and a preference inventory consisting of skilled behavior items), the correlation presumably would be lower.

Here too, as Steenhuis and Bryden (1989) have suggested, a factorial approach to the study of hand preference, using a more comprehensive questionnaire, may provide clues about the nature of performance tasks. For example, are there one or more specific preference factors that show a strong correlation with a specific performance task, whereas other factors do not? If so, are these relationships different between right- and left-handers?

Purposes of the Study

As we have seen, some researchers assert that handedness is unifactorial, whereas others argue that it is multifactorial and even the latter do not agree among themselves as to the number and types of factors involved. It has been hypothesized that the factorial nature of handedness might be influenced by the number and the type of questions, the percentage of left-handers in the sample, and the kinds of societies from which respondents are recruited. It also has been suggested that the way that factor analysis has been used not only in the purely technical sense but in the conceptual sense as well raises doubts about these results. Therefore, in order to better understand the factor structure of hand preference, we need to use factor analysis appropriately along with a more comprehensive questionnaire integrating recent conceptual advances in our understanding of handedness. We also need to better understand whether and how the inclusion of left-handers in the factor analysis affects the results. Finally, we need to consider whether and how sex and FS, along with individual histories of exposure to pressures to change hand preference, might be related to the factor structure of handedness, how handedness is related to other expressions of lateral preference in the factor structure, and how the factor structure might offer clues about the nature of performance tasks. The current study was designed to address these needs.

The first purpose of this study was to administer a new and comprehensive handedness questionnaire, to determine the factor structure of handedness by confirmatory factor analysis, and to compare the factor structure with those found in previous studies.

The second purpose was to identify and compare the characteristics of the right-handers and the left-handers in the factor structure.

The third purpose was to compare the factor structure of males with that of females. The study also asked whether specific factors show the differences of direction or degree of handedness between men and women, between FS+ and FS-, or between hand-change and no-change group. It also looked for interactions between handedness and sex, FS, or hand-change. Finally, the study examined the relationships between handedness and other lateralities, and between hand preference and hand performance relating to the factor structure of handedness.

METHOD

Subjects

The sample consisted of 502 undergraduate college students (252 males, 250 females) who had enrolled in the Human Subject Pool in the Department of Psychology, Michigan State University, and who volunteered for the study by signing the posted sign-up sheet. No one was included who reported having any uncorrected sensory (vision and hearing) deficits or any motor and sensory deficits involving the hands or feet of a sort that could have influenced their limb preference. The subjects' mean age was 20.8 years (s.d. = 2.8).

Of the entire sample, 82.7% of the subjects were Caucasian, 7.6% were African-American, and 3.4% were Asian-American. The remaining 6.3% were other races and/or ethnic origin groups such as Hispanic, Native-American (i.e., aboriginal), or Pacific-American. The subjects were enrolled in one of several large introductory (freshman and sophomore level) psychology classes; their academic majors were very diverse, embracing over 43 different majors in 9 different colleges, including social science, education, medicine, engineering, business, natural science, arts and letters, communication arts and science, and nursing.

As a part of the battery of tests administered, subjects were asked for information about their parents' education and occupation. For educational level, the six standard categories used by the United States Department of Labor (Lansky, Feinstein, & Peterson, 1988) were used. Most of the parents (96%) had high school diplomas, with 78.7% of the fathers and 69.7% of the mothers having college degrees or some work at the university level. To measure socioeconomic status (SES) based on occupation, the Duncan Socioeconomic Index for Occupations (Stevens & Featherman, 1980) was used. The median SES scores were 49.1 and 35.3

for the fathers and mothers, respectively. These SES scores tell us that the average subjects came from lower middle to middle class backgrounds.

Materials and Procedures

Subjects completed four questionnaires (Personal Data Questionnaire, Lateral Preference Questionnaire, Hand Preference Change Questionnaire, and Family Handedness Questionnaire) and one performance test (Dot-Filling Test). Specimen copies are provided in Appendix A. Testing was conducted in a small classroom in the Psychology Research Building. Subjects were tested in small groups of 2 to 20 depending on the number who signed up to be tested for any particular testing session. Each subject received 2 packets of questionnaires, one for the subject and the other for the subject's parents. After receiving a brief oral description of the study by the investigator, subjects were instructed to fill out the questionnaires in the first packet in the following order: Personal Data Questionnaire, Lateral Preference Questionnaire, Hand Preference Change Questionnaire, and Family Handedness Questionnaire. After all subjects, working at their own pace, completed these four questionnaires, the Dot-Filling Test was administered as a group test. Finally, the subjects received instructions about the second packet -- the parents' questionnaire. The entire testing period took approximately 40 minutes.

Personal Data Questionnaire (Appendix A, pp. 172-173)

The Personal Data Questionnaire asked about the subject's age, sex, ethnicity, academic major, and parents' educational level and occupation. It also asked about writing hand and for an estimate of overall handedness from the following alternatives: (a) Right-handed and strongly so, (b) Right-handed but only moderately so, (c) Left-handed but only moderately so, and (d) Left-handed and strongly so (Chapman & Chapman, 1987).

<u>**Lateral Preference Questionnaire**</u> (Appendix A, pp. 174-178)

The Lateral Preference Questionnaire consisted of 55 items about handedness, 5 items about footedness, 4 items about earedness, and 7 items about eyedness. Based on the combinations of the handedness factors suggested in previous studies, *a priori* clusters were created consisting of 8 handedness clusters and 3 other clusters for footedness, earedness, and eyedness (Table 1).

Cluster 1 consisted of skilled, more distal unimanual acts requiring low to moderate strength (e.g., writing, hammering, sewing). Cluster 2 consisted of skilled, more proximal, unimanual acts requiring low to moderate strength (e.g., throwing a ball or dart). Clusters 3 and 4 both consisted of unskilled more distal, unimanual acts requiring low strength (e.g., for Cluster 3, waving good-bye and knocking at the door; for Cluster 4, "picking-up" small objects). Cluster 5 consisted of unskilled, proximal, unimanual acts requiring high strength (e.g., carrying a heavy suitcase). Cluster 6 consisted of unskilled, proximal, bimanual acts requiring low strength (e.g., mop, broom, spade). Cluster 7 consisted of skilled, more proximal, bimanual acts requiring high strength (e.g., bat, axe). Cluster 8 consisted of skilled, distal, bimanual acts requiring high strength (e.g., unscrewing a tight jar cap). Items that could be assigned to each cluster were selected from previous questionnaires (e.g., Beukelaar & Kroonenberg, 1983; Dean, 1978a; Healey et al., 1986; Oldfield, 1971; Provins et al., 1984; Steenhuis & Bryden, 1989). New items also were added in sufficient number to balance the number of items across clusters. Subjects rated their lateral preference for each item on a 5-point scale: always left / usually left / both hands equally often (either) / usually right / always right. The items were scored from 1 (always left) to 5 (always right). To avoid any problems possibly arising from the subjects' inattentiveness or misreading or misunderstanding of questions, all items comprising each category were presented together under a subtitle

Table 1

A Priori Clusters

Clusters 1-8: Handedness. Hand preference items comprising 8 different clusters according to the degree of skill required (skilled/unskilled); the degree to which the task involves distal musculature relative to proximal musculature (Distal/Proximal=distal prominant, Proximal/Distal=proximal prominant); the strength required; and whether the task is predominantly unimanual or bimanual.

Clusters 9-11: Other Lateralities.

Cluster	Item #	Skilled /Unskilled	Distal /Proximal	Strength	Unimanual /Bimanual
1	1-10	Skilled	Distal /Proximal	Low to Moderate	Unimanual
2	16-25	Skilled	Proximal /Distal	Low to Moderate	Unimanual
3	30-39	Unskilled	Distal	Low	Unimanual
4	47-56	Unskilled	Distal	Low	Unimanual
5	57-61	Unskilled	Proximal	High	Unimanual
6	62-64	Unskilled	Proximal	Low	Bimanual
7	65-66	Skilled	Proximal /Distal	High	Bimanual
8	67-71	Unskilled	Distal	High	Bimanual /Unimanual
9	11-15	Footedness Cluster			
10	26-29	Earedness Cluster			
11	40-46	Eyedness Cluster			

that identified the general contents of the items. For example, included under the subtitle, "When you pick up an object, which hand would you use to -- ," were items such as "pick up a piece of paper," "pick up a marble," and "pick up a glass of water."

Five footedness questions (Cluster 9), four earedness questions (Cluster 10), and seven eyedness questions (Cluster 11) were included in order to examine the relationship between handedness and other expressions of lateral preference in the factor structure. These items were chosen from previous questionnaires (e.g., Chapman, Chapman, & Allen, 1987; Coren & Porac, 1978; Dean, 1978a; Porac et al., 1980; Raczkowski et al., 1974).

After completing the questionnaire, subjects were asked whether they suffered from any physical or other handicaps that might have influenced their answers to any items on the questionnaire.

Hand Preference Change Questionnaire (Appendix A, pp. 179-181)

The Hand Preference Change Inventory was designed to obtain information about attempts to change handedness and the circumstances behind these attempts. The inventory was based on one used by Porac et al. (1986) but was revised to provide more detailed information. Specifically, questions were added asking when the hand change was accomplished and why someone (including the subjects themselves) wanted to change the subjects' handedness.

Family Handedness Questionnaire (Appendix A, pp. 182-183)

The Family Handedness Questionnaire asked for information about the age, sex, writing hand and overall handedness of the subjects' immediate biological relatives (parents and siblings) and grandparents. Subjects also were asked whether any of their relatives had been forced to change their preferred hand for social or physical reasons. Information on these family members was used to generate the following variables (Bishop, 1980; Leiber & Axelrod, 1981; Spiegler & Yeni-Komshian, 1983):

1. Familial Sinistrality: 2 levels: absent, present

2. Grandparent-Parent Familial Sinistrality: 2 levels: absent, present

3. Parental Handedness: 4 levels: RR, LR, RL, LL

4. Sibling Sinistrality: 2 levels: absent, present

5. Familial Handedness: 4 levels: all dextral, nonright-handed sibling(s) only, nonright-handed parent(s) only, nonright-handed sibling(s) and nonright-handed parent(s)

After completing their own questionnaires, subjects were asked about their parents' marital status. If the biological parents were not divorced or if they had lived together with the subject until the subject was at least 8 years old, the investigator asked the subject for permission to send the questionnaire to the parents. Subjects who agreed were asked to write their parents' names and address(es) on envelope(s) that were included in the subject's questionnaire packet. A short version of the Lateral Preference Questionnaire, together with a letter of introduction and explanation, then was sent to the parents (Appendix B). This procedure was undertaken in order to obtain more accurate information about parental handedness than the subjects themselves might have been able to provide. The letter of introduction instructed the parents to return the questionnaire directly to the investigator in a stamped, self-addressed envelope that was included with the parents' questionnaire.

<u>Dot-Filling Test</u> (Appendix A, pp. 184-185)

The Dot-Filling Test, developed as a paper-and-pencil group test of manual proficiency (Tapley & Bryden, 1985), was used as a hand performance measure. The test consists of patterns of ½ cm diameter circles drawn in 8 columns on a sheet of paper. Subjects were instructed to make a dot with a pencil in each small circle and to follow the pattern as quickly as possible. The instruction emphasized accuracy as well as speed by noting that the dots must be inside the circle in order to be scored. Four trials were given, with 20 seconds allotted for each trial. Subjects were instructed to use their dominant hand on trials 1 and 4 and their nondominant hand on trials 2 and 3. For scoring, the number of circles properly filled was counted for each trial. Performance differences between hands were expressed as a dominance ratio (Borod et al., 1984) as follows: Dominant hand minus non-dominant hand divided by dominant hand plus non-dominant hand (D-ND / D+ND). Positive scores reflect better performance by the dominant hand.

RESULTS AND DISCUSSION

Demographic Data

Age

Of the entire sample, 96.6% were in their late teens or early twenties (range: 17-25 years old) and the rest were older. No significant relationship was found between handedness and age.

Sex

Sex differences in handedness will be discussed later.

Race and Ethnicity

Of the entire sample, 82.7% were Caucasian (see p. 55). There were too few persons of other races or ethnic groups to permit comparisons.

Academic Major

As noted previously (see p. 55), students' academic majors were extremely diverse, and were not concentrated in any specific area. For this reason, the numbers of subjects in each major were insufficient to allow comparisons between academic majors.

Socioeconomic Status (SES)

As already noted, previous analyses of the demographics of handedness (e.g., Lansky et al., 1988; Peterson, 1979; Shettel-Neuber & O'Reilly, 1983; Thompson & Marsh, 1976) have yielded very inconsistent results. It has been emphasized that studies of the demography of handedness should be based on clearly defined total populations or on random samples drawn from such populations (Lansky et al., 1988). The current sample did not satisfy this condition inasmuch as it consists of undergraduate college students, the vast majority young, white, and middle class. Nevertheless, an attempt was made to examine the relationship of SES to handedness by using the parents' education and occupation as indirect measures. The distributions of parents' education levels and SES scores based on parents' occupation were divided as close as possible to the median for the total sample. There were no statistically significant relationships between subjects' self-classified handedness and parents' education level.

Classification of Handedness

Results[5]

General handedness; self-classification. Of the total sample of 502 subjects, 500 specified their general handedness and two did not (See Table 2). These last two subjects, however, were included for all further analyses except for those analyses that used self-classified handedness as a variable. Of the 500 subjects who specified their general handedness, there were 439 right-handers (87.8%) and 61 left-handers (12.2%).

Writing hand. Of the total sample of 502 subjects, 442 subjects (88%) reported that they wrote with their right hand, 58 (11.6%) reported that they used their left hand, and two reported that they used both hands equally.

Lateral Preference Questionnaire. For the 55 handedness items included in the Lateral Preference Questionnaire, scores could range from 55 (exclusive left-hand use for all items, i.e., 55 × 1) to 275 (exclusive right-hand use for all items, i.e., 55 × 5). The actual range was from 59 to 275. The distribution (see Figure 1) did not show a clear bimodal (or trimodal) distribution. Therefore, the cutting points for designating a subject as right-handed, left-handed, or ambidextrous are necessarily arbitrary. Most previous studies (e.g., Healey et al., 1986: Porac & Coren, 1981; Steenhuis & Bryden, 1989) have used the middle point on the scale. Thus, on a 5-point scale, with 3 as the reference point, they classify subjects whose average total handedness

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[5] The numbers of subject reported in this section are maximum values and are different from the figures shown in Tables 2, 3, and 4 because not every subject answered every question.

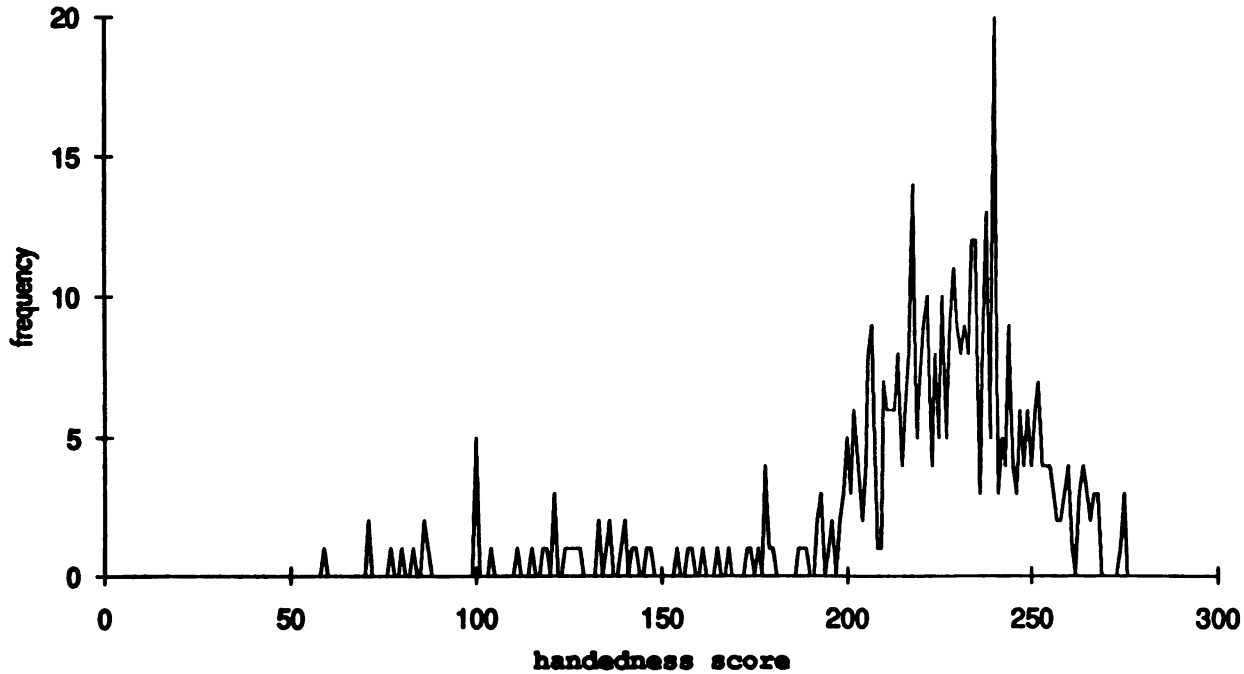


Figure 1. Frequency distribution (number of subjects) of hand preference scores of 502 subjects. Minimum score = 55 (55 items x 1); Maximum score = 275 (55 items x 5).

Table 2

Frequency Distribution of Subjects' Writing Hand Tabulated Against Subjects' Self-Classification of Handedness

	Writing Hand			
General Handedness	Left	Either	Right	Total
Left	56 (91.8%)	0 (0.0%)	5 (8.2%)	61 (12.2%)
Right	2 (0.5%)	1 (0.2%)	436 (99.3%)	439 (87.8%)
Total	58 (11.6%)	1 (0.2%)	441 (88.2%)	500

Table 3

Frequency Distribution of Subjects' Handedness Based on Hand Preference Scores Tabulated Against Subjects' Self-Classification of Handedness

	Preference Score			
General Handedness	Left-hander (Score<3)	Ambidextrous (Score=3)	Right-hander (Score>3)	Total
Left	43 (76.8%)	0 (0.0%)	13 (23.2%)	56 (11.7%)
Right	0 (0.0%)	0 (0.0%)	421 (100.0%)	421 (88.3%)
Total	43 (9.0%)	0 (0.0%)	434 (91.0%)	477

Table 4

Frequency Distribution of Subjects' Handedness Based on Hand Preference Scores Tabulated Against Subjects' Writing Hand

	Preference Score			
Writing Hand	Left-hander (Score<3)	Ambidextrous (Score=3)	Right-hander (Score>3)	Total
Left	41 (77.4%)	0 (0.0%)	12 (22.6%)	53 (11.1%)
Either	0 (0.0%)	0 (0.0%)	2 (100.0%)	2 (0.4%)
Right	3 (0.7%)	0 (0.0%)	421 (99.3%)	424 (88.5%)
Total	44 (9.2%)	0 (0.0%)	435 (90.8%)	479

score is less than 3 as left-handed, subjects whose score is greater than 3 as right-handed, and subjects whose score is equal to 3 as ambidextrous. Applying the same rule to the present data, 435 (90.8%) of the 479 subjects who answered all of the 55 handedness items were classified as right-handed, and 44 (9.2%) were classified as left-handed. No one was classified as ambidextrous.

Table 3 shows the frequency and percentage of subjects classified as right-handed, ambidextrous, or left-handed by the handedness questionnaire for each of the above-named categories. Of the 421 subjects who called themselves right-handed (either strongly right-handed or moderately right-handed) and answered all of the 55 items on the handedness questionnaire, 100% were also right-handed according to the questionnaire score, whereas of the 56 subjects who called themselves left-handed and answered all of the 55 handedness items, only 76.8% (43 of 56 subjects) were left-handed. Table 4 shows the relationship between writing hand and handedness categorization using scores on the handedness questionnaire. Among those 424 subjects who said that they wrote with their right hand and answered all of the 55 handedness items, 421 (99.3%) were right-handed on the questionnaire, and 3 (0.7%) were left-handed, whereas among those 53 subjects (11.1%) who said that they wrote with their left hand, 41 (77.4%) were left-handed on the questionnaire, and 12 (22.6%) were right-handed.

Discussion

As noted earlier, the first requirement for handedness researchers is to decide how to classify handedness. The writing hand has been the most commonly used behavioral index. McManus (1984) called it the best indicator on the grounds that it is extremely stable and that no one is equally proficient with both hands. However, writing hand alone may not suffice because it is subject to social or cultural pressures (Thompson & Marsh, 1976; see review in Harris, 1990b). This proved to be so even in the current sample of college students living in a "liberal" country.

Of the 61 self-classified left-handers, 5 (8.2%) reported that they used their right hand for writing (see Table 2).

Many investigators have categorized their subjects as right- or left-handed using only self-classification measures. This practice has been criticized by investigators who believe that self-classification is "subjective" and "open to error" (Annett, 1970a; Benton et al., 1962; Crovitz & Zener, 1962; Provins & Cunliffe, 1972). Binary self-classification also has been criticized as "too global" a measure to capture the range of lateral preference observed among non-right-handers (Annett, 1985; Connolly & Bishop, 1992).

The current results support this criticism by showing the discrepancy between subjects' self-classification and handedness categorization using the questionnaire scores. The discrepancy was particularly clear for the 56 subjects who classified themselves as left-handed and answered all of the 55 handedness items, since 13 (23.2%) proved to be right-handed according to their questionnaire scores.

Accepting all these points, it still is hard to say, definitively, that the one method is better than the other; just as subjects' different criteria for classifying their handedness contribute to this discrepancy, so would the use of arbitrary cutting points for categorizing subjects based on questionnaire scores. One of the initial motives for the development of handedness inventories was dissatisfaction with a simple dichotomous categorization, along with the conviction that a quantitative method would yield a more sensitive index. However, even those researchers who use an inventory to quantify handedness commonly revert to a categorical classification, dividing subjects by arbitrary cut-off points, which vary from study to study (Bishop, 1990).

Different classifications can yield different prevalence figures for right-, left-, and mixed-handers. In the absence of an adequate taxonomy of handedness phenotype or a clear understanding of mechanism, however, it is difficult to argue that one method or another is necessarily superior.

Factor Analysis

Scores on the 71-item Lateral Preference Questionnaire ranged from 75 to 355. Figure 2 shows a highly negatively skewed distribution of lateral preference scores from the total subject sample. The response distributions for each item are summarized in Table 5 and Table 6 for self-classified right- and left-handers separately.

A priori cluster analysis

As the first step for the confirmatory factor analysis of the data, an *a priori* cluster analysis was performed using a confirmatory factor analysis program in PACKAGE (Hamilton & Hunter, 1988). The *a priori* clusters used in this analysis are shown in Table 1. Although the results showed that the *a priori* clusters fit the data very well, examination of the homogeneity of item contents, internal consistency, external consistency, and the correlations between clusters suggested additional qualifications. The results revealed a subcluster consisting of two items, writing and drawing, originally belonging to Cluster 1. The results thus suggested that this subcluster should be separated from Cluster 1. The *a priori* cluster analysis also revealed several items with low item reliabilities and low item-cluster correlations. These included items 23 (bounce a basketball), 24 (catch a baseball), 36 (snap fingers), and 59 (hold an open umbrella). It also revealed two other items -- items 30 (flip a coin) and 68 (hold a heavy object) -- that had higher correlations with other clusters than with the original cluster to which they belonged. The results suggest that these last two items were misplaced.

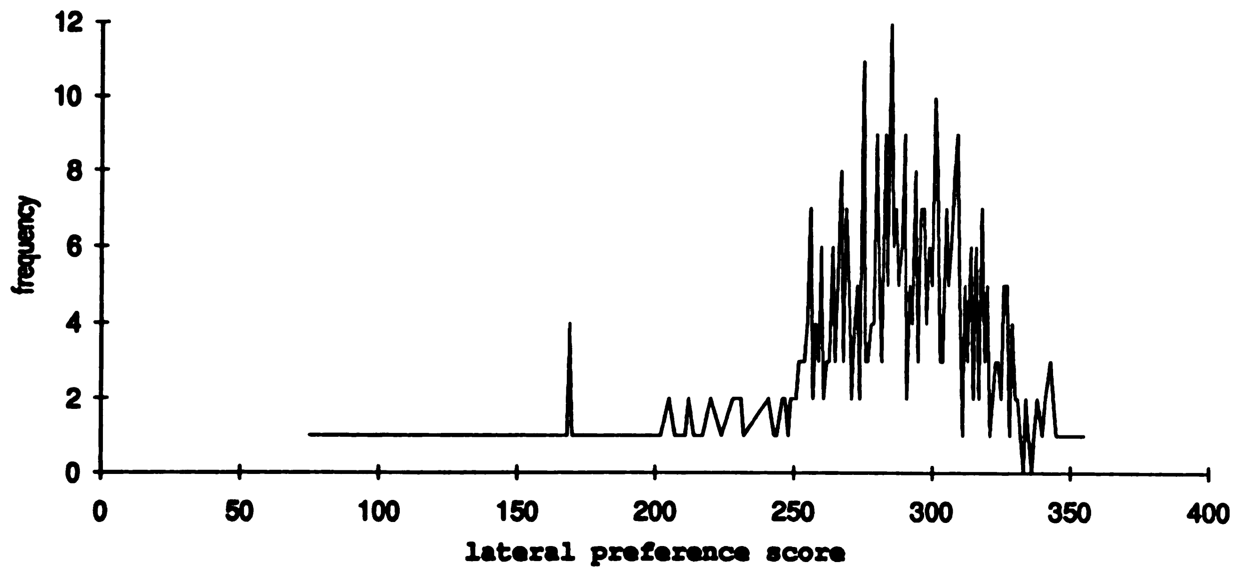


Figure 2. Frequency distribution (number of subjects) of the lateral preference scores of 502 subjects. Minimum score (lowest degree of lateralization) = 71 (71 items x 1); Maximum score (highest degree of lateralization) = 355 (71 items x 5).

Table 5

Distribution of Percentage of Responses on the Laterality Items in the Right-Handers, Where 1=Always Left, 2=Usually Left, 3=Either, 4=Usually Right, and 5=Always Right

	Male						Female					
Item	n	1	2	3	4	5	n	1	2	3	4	5
1.WRITE	222	0.9	0.0	0.0	1.8	97.3	217	0.0	0.0	0.5	0.0	99.5
2.DRAW	222	0.9	0.0	0.5	4.1	94.6	217	0.0	0.5	0.0	4.1	95.4
3.SCISSORS	222	0.0	0.0	5.4	24.3	70.3	217	0.0	0.0	1.8	12.0	86.2
4.TOOTHBRUSH	221	0.9	0.0	10.0	19.9	69.2	217	0.5	0.0	8.3	23.0	68.2
5.SPOON	222	1.4	0.5	9.5	20.3	68.5	217	0.0	1.8	5.5	16.1	76.5
6.SEW	218	0.5	0.0	2.3	17.0	80.3	217	0.5	0.5	3.2	11.5	84.3
7.HAMMER	221	0.9	0.0	4.1	17.2	77.8	217	0.5	0.5	1.8	11.1	86.2
8.KNIFE	222	0.9	0.9	7.2	18.9	72.1	217	0.9	1.8	5.1	16.1	76.0
9.SCREWDRIVER	222	0.0	0.5	12.2	30.6	56.8	217	0.0	0.5	4.1	19.8	75.6
10.ERASER	221	1.4	0.5	13.1	26.7	58.4	216	0.9	0.9	10.6	26.9	60.6
16.THROW	222	0.5	0.0	0.5	9.9	89.2	217	0.0	0.0	0.5	16.6	82.9
17.SHOOT	222	0.0	0.0	7.7	23.0	69.4	216	0.0	0.0	5.6	26.4	68.1
18.BOWLING	222	0.0	0.5	2.3	6.3	91.0	217	0.0	0.0	1.8	6.9	91.2
19.DART	222	0.0	0.0	0.9	12.2	86.9	217	0.0	0.0	1.8	9.2	88.9
20.VOLLEY	222	0.0	0.9	2.7	5.0	91.4	217	0.0	0.0	0.9	10.6	88.5
21.PINGPONG	222	0.5	0.0	4.5	17.1	77.9	217	0.5	0.0	3.2	11.1	85.3
22.TENNIS	220	0.5	0.0	4.5	16.4	78.6	217	0.5	0.5	2.8	11.5	84.8
23.BASKETBALL	221	0.0	0.5	53.4	30.8	15.4	217	0.0	0.9	37.3	34.6	27.2
24.CATCHBALL	222	2.3	5.0	41.0	26.1	25.7	217	0.5	2.3	19.8	33.2	44.2
25.FRISBEE	222	2.3	0.5	8.1	21.2	68.0	217	0.5	0.9	4.1	24.4	70.0
30.FLIPCOIN	222	0.0	0.5	14.0	43.7	41.9	217	0.0	0.0	10.6	37.3	52.1
31.WAVE	222	0.0	1.8	41.9	42.3	14.0	217	0.0	0.5	40.6	42.9	16.1
32.POINT	222	0.0	2.7	35.6	45.5	16.2	217	0.0	0.9	38.7	44.2	16.1
33.KNOCK	222	0.0	0.9	24.3	56.3	18.5	216	0.0	0.0	26.4	50.5	23.1
34.OFFER	222	0.5	2.7	37.4	43.2	16.2	217	0.0	1.8	37.8	44.7	15.7
35.PHONE	222	1.4	0.9	14.9	48.6	34.2	217	0.0	2.3	11.1	44.7	41.9
36.SNAPFINGER	222	2.7	2.3	51.4	27.9	15.8	217	3.2	2.8	39.2	29.5	25.3
37.SWITCH	222	0.0	0.0	69.8	24.3	5.9	216	0.0	0.9	56.5	31.0	11.6
38.DOORBELL	222	0.0	0.5	48.2	41.0	10.4	217	0.5	0.9	41.0	39.2	18.4
39.SALTSHAKER	222	0.0	1.4	26.6	48.2	23.9	217	0.0	0.9	18.4	45.6	35.0
47.PAPER	222	0.5	1.4	41.9	43.2	13.1	217	0.0	0.9	35.9	50.2	12.9
48.WALLET	222	0.5	1.8	42.3	42.3	13.1	217	0.0	1.8	39.2	47.0	12.0
49.BASEBALL	222	0.5	0.9	26.6	52.7	19.4	217	0.0	1.4	18.4	60.8	19.4
50.MARBLE	222	0.0	0.5	33.8	50.5	15.3	217	0.0	1.4	26.3	52.5	19.8
51.JAR	221	0.0	1.4	43.9	43.4	11.3	217	0.0	0.5	33.6	48.8	17.1
52.DIME	221	0.0	1.8	30.8	52.5	14.9	217	0.0	1.4	31.3	52.5	14.7
53.PBACKBOOK	222	0.0	2.3	49.1	38.7	9.9	217	0.0	1.8	43.3	42.9	12.0
54.CLIP	222	0.5	1.4	31.5	52.3	14.4	216	0.0	1.9	31.5	50.0	16.7
55.GLASS	222	0.0	2.3	40.1	42.8	14.9	217	0.0	1.8	25.3	51.6	21.2

(Table Continued)

Table 5. (Cont'd)

Item	Male						Female					
	n	1	2	3	4	5	n	1	2	3	4	5
56.PIN	222	0.5	0.9	25.2	54.1	19.4	217	0.0	0.5	22.6	53.9	23.0
57.PICKSCASE	221	0.0	2.7	14.5	58.8	24.0	217	0.0	1.4	6.9	55.8	35.9
58.CARRYBCASE	221	0.0	4.1	25.8	51.1	19.0	217	0.0	0.9	17.1	45.2	36.9
59.UMBRELLA	221	1.4	9.5	44.8	31.2	13.1	217	0.9	8.8	32.7	33.2	24.4
60.BUCKET	221	0.0	3.2	34.4	46.6	15.8	217	0.0	1.4	24.4	43.8	30.4
61.CARRYSCASE	222	0.0	3.2	30.8	45.2	20.8	217	0.0	2.3	18.9	47.0	31.8
62.SPADE	222	5.4	3.6	8.6	36.0	46.4	217	4.6	6.9	3.7	35.9	48.8
63.BROOM	222	7.7	11.3	18.9	32.9	29.3	217	4.6	11.5	13.8	35.0	35.0
64.MOP	222	6.3	9.0	19.8	36.0	28.8	217	4.6	11.5	11.1	36.9	35.9
65.BAT	222	3.2	3.2	7.2	28.4	58.1	217	0.9	1.4	6.0	22.1	69.6
66.AXE	222	2.3	2.3	7.2	36.5	51.8	217	0.0	0.9	1.8	29.0	68.2
67.OPENCAN	221	2.3	3.2	21.3	48.4	24.9	217	0.9	0.9	11.5	41.5	45.2
68.HEAVY	220	0.0	1.8	23.2	56.4	18.6	217	0.0	0.5	18.4	47.5	33.6
69.JARCAP	222	4.5	11.7	17.1	38.3	28.4	217	5.1	3.2	10.1	34.6	47.0
70.BOTTLETOP	221	0.9	7.7	16.3	45.7	29.4	215	2.3	1.9	8.4	40.0	47.4
71.STRENGTH	221	0.9	2.3	13.1	44.8	38.9	217	0.5	0.5	6.5	38.2	54.4
11.KICK	222	1.4	2.7	25.7	39.2	31.1	217	0.5	0.0	12.0	39.6	47.9
12.STEPSTOOL	222	2.3	5.4	33.8	40.1	18.5	217	0.9	3.7	27.2	43.8	24.4
13.TOE	222	0.0	3.2	50.5	26.1	20.3	217	0.5	2.3	39.6	32.7	24.9
14.HOP	219	1.8	6.4	51.1	26.5	14.2	216	0.9	3.2	52.8	26.4	16.7
15.BALANCE	219	3.7	13.2	28.3	27.9	26.9	217	1.4	9.7	26.3	34.6	28.1
26.CONVERSE	222	2.7	5.4	46.4	36.5	9.0	217	0.0	5.1	31.3	46.1	17.5
27.HEARTBEAT	222	1.8	8.1	38.7	38.3	13.1	217	0.0	6.5	30.9	46.1	16.6
28.EARPHONE	221	1.8	8.1	47.1	31.2	11.8	217	0.0	5.1	46.5	34.6	13.8
29.SOFTSOUND	222	1.8	10.4	45.9	30.2	11.7	217	0.9	7.4	40.6	38.7	12.4
40.PEEP	220	5.0	12.7	20.0	44.5	17.7	217	1.8	14.3	17.5	42.4	24.0
41.BOTTLE	220	3.6	11.8	25.0	41.4	18.2	217	1.4	11.5	19.8	42.4	24.9
42.RIFLE	220	6.8	6.4	4.1	24.5	58.2	216	2.8	12.5	6.0	33.8	44.9
43.TELESCOPE	220	6.4	6.4	13.2	35.9	38.2	217	2.3	12.0	9.7	39.6	36.4
44.CAMERA	219	6.8	5.0	6.8	36.1	45.2	217	3.7	8.3	6.0	30.9	51.2
45.NEEDLE	217	5.1	7.8	16.1	34,6	36.4	216	3.7	11.6	11.1	33.8	39.8
46.MICROSCOPE	220	6.4	8.2	16.8	31.4	37.3	217	2.3	9.7	15.2	37.8	35.0

Table 6

Distribution of Percentage of Responses on the Laterality Items in the Left-Handers, Where 1=Always Left, 2=Usually Left, 3=Either, 4=Usually Right, and 5=Always Right

	Male						Female					
Item	n	1	2	3	4	5	n	1	2	3	4	5
1.WRITE	29	86.2	0.0	0.0	0.0	13.8	31	100.0	0.0	0.0	0.0	0.0
2.DRAW	29	86.2	0.0	0.0	0.0	13.8	31	100.0	0.0	0.0	0.0	0.0
3.SCISSORS	29	41.6	6.9	17.2	13.8	20.7	32	37.5	3.1	15.6	6.3	37.5
4.TOOTHBRUSH	29	44.8	13.8	3.4	3.4	13.8	32	62.5	15.6	9.4	3.1	9.4
5.SPOON	29	65.5	13.8	3.4	3.4	13.8	32	78.1	15.6	0.0	0.0	6.3
6.SEW	29	65.5	6.9	6.9	3.4	17.2	32	62.5	15.6	6.3	6.3	9.4
7.HAMMER	29	58.6	3.4	13.8	6.9	17.2	32	53.1	9.4	12.5	6.3	18.8
8.KNIFE	29	58.6	10.3	10.3	3.4	17.2	32	53.1	6.3	15.6	6.3	18.8
9.SCREWDRIVER	29	37.9	10.3	13.8	17.2	20.7	32	34.4	21.9	21.9	9.4	12.5
10.ERASER	29	58.6	13.8	13.8	3.4	10.3	32	78.1	15.6	6.3	0.0	0.0
16.THROW	29	75.9	3.4	0.0	0.0	20.7	32	46.9	12.5	3.1	9.4	28.1
17.SHOOT	29	41.4	10.3	20.7	13.8	13.8	32	41.9	25.8	6.5	16.1	9.7
18.BOWLING	29	79.3	0.0	10.3	0.0	10.3	32	56.3	3.1	6.3	0.0	34.4
19.DART	29	69.0	13.8	3.4	0.0	13.8	32	64.5	3.2	6.5	0.0	25.8
20.VOLLEY	29	72.4	6.9	3.4	3.4	13.8	32	50.0	6.3	3.1	9.4	31.3
21.PINGPONG	29	62.1	6.9	10.3	3.4	17.2	32	56.3	12.5	12.5	0.0	18.8
22.TENNIS	29	65.5	3.4	6.9	10.3	13.8	32	53.1	12.5	12.5	3.1	18.8
23.BASKETBALL	29	13.8	27.6	48.3	3.4	6.9	32	15.6	6.3	46.9	12.5	18.8
24.CATCHBALL	29	27.6	17.2	34.5	10.3	10.3	32	25.0	34.4	6.3	18.8	15.6
25.FRISBEE	29	41.4	20.7	3.4	13.8	20.7	32	40.6	12.5	9.4	15.6	21.9
30.FLIPCOIN	29	31.0	17.2	20.7	20.7	10.3	32	25.0	25.0	15.6	18.8	15.6
31.WAVE	29	27.6	24.1	31.0	13.8	3.4	32	9.4	31.3	31.3	12.5	15.6
32.POINT	29	17.2	34.5	31.0	13.8	3.4	32	9.4	25.0	40.6	18.8	6.3
33.KNOCK	28	25.0	21.4	39.3	10.7	3.6	32	18.8	12.5	31.3	28.1	9.4
34.OFFER	29	13.8	20.7	55.2	6.9	3.4	31	3.2	29.0	38.7	19.4	9.7
35.PHONE	29	27.6	24.1	13.8	17.2	17.2	32	21.9	12.5	12.5	34.4	18.8
36.SNAPFINGER	29	10.3	6.9	48.3	13.8	20.7	32	12.5	9.4	59.4	12.5	6.3
37.SWITCH	29	13.8	10.3	55.2	20.7	0.0	32	9.4	15.6	62.5	9.4	3.1
38.DOORBELL	29	13.8	20.7	41.4	24.1	0.0	32	9.4	18.8	40.6	25.0	6.3
39.SALTSHAKER	29	31.0	31.0	24.1	10.3	3.4	32	25.0	40.6	18.8	15.6	0.0
47.PAPER	29	13.8	27.6	44.8	10.3	3.4	32	3.1	34.4	43.8	15.6	3.1
48.WALLET	29	13.8	17.2	48.3	13.8	6.9	32	3.1	34.4	46.9	12.5	3.1
49.BASEBALL	29	20.7	37.9	27.6	3.4	10.3	32	0.0	31.3	40.6	25.0	3.1
50.MARBLE	29	10.3	24.1	51.7	0.0	13.8	32	3.1	34.4	46.9	12.5	3.1
51.JAR	29	13.8	17.2	58.6	3.4	6.9	32	0.0	34.4	53.1	9.4	3.1
52.DIME	29	13.8	24.1	48.3	6.9	6.9	32	6.3	28.1	50.0	15.6	0.0
53.PBACKBOOK	29	10.3	20.7	55.2	13.8	0.0	32	0.0	37.5	56.3	3.1	3.1
54.CLIP	29	17.2	24.1	41.4	10.3	6.9	32	3.1	34.4	50.0	9.4	3.1
55.GLASS	29	20.7	27.6	44.8	0.0	6.9	32	0.0	43.8	40.6	12.5	3.1

(Table Continued)

Table 6. (Cont'd)

	Male						Female					
Item	n	1	2	3	4	5	n	1	2	3	4	5
56.PIN	29	20.7	37.9	27.6	6.9	6.9	32	6.3	40.6	37.5	9.4	6.3
57.PICKSCASE	29	31.0	27.6	20.7	17.2	3.4	32	12.5	37.5	21.9	18.8	9.4
58.CARRYBCASE	29	31.0	31.0	24.1	10.3	3.4	32	12.5	37.5	18.8	25.0	6.3
59.UMBRELLA	29	24.1	41.4	17.2	17.2	0.0	32	9.4	31.3	21.9	28.1	9.4
60.BUCKET	29	17.2	31.0	37.9	10.3	3.4	32	9.4	34.4	21.9	28.1	6.3
61.CARRYSCASE	29	17.2	41.4	34.5	6.9	0.0	32	9.4	37.5	18.8	28.1	6.3
62.SPADE	29	44.8	20.7	6.9	10.3	17.2	32	25.0	40.6	6.3	15.6	12.5
63.BROOM	29	44.8	24.1	17.2	6.9	6.9	32	31.3	40.6	6.3	15.6	6.3
64.MOP	29	44.8	27.6	10.3	6.9	10.3	32	31.3	43.8	3.1	18.8	3.1
65.BAT	29	37.9	20.7	0.0	17.2	24.1	32	18.8	12.5	3.1	31.3	34.4
66.AXE	29	34.5	24.1	6.9	17.2	17.2	32	15.6	28.1	3.1	25.0	28.1
67.OPENCAN	29	17.2	27.6	24.1	17.2	13.8	32	15.6	21.9	18.8	34.4	9.4
68.HEAVY	29	20.7	27.6	37.9	10.3	3.4	32	3.1	37.5	31.3	21.9	6.3
69.JARCAP	29	34.5	20.7	17.2	17.2	10.3	32	28.1	25.0	6.3	28.1	12.5
70.BOTTLETOP	28	21.4	17.9	32.1	14.3	14.3	32	28.1	25.0	6.3	28.1	12.5
71.STRENGTH	29	37.9	31.0	6.9	17.2	6.9	32	29.0	29.0	6.5	32.3	3.2
11.KICK	28	32.1	14.3	10.7	25.0	17.9	32	12.5	21.9	12.5	21.9	31.3
12.STEPSTOOL	28	17.9	17.9	42.9	17.9	3.6	32	18.8	12.5	28.1	31.3	9.4
13.TOE	28	17.9	17.9	53.6	7.1	3.6	32	15.6	25.0	31.3	18.8	9.4
I4.HOP	28	10.7	17.9	50.0	17.9	3.6	32	6.3	15.6	53.1	12.5	12.5
15.BALANCE	27	33.3	14.8	40.7	7.4	3.7	32	12.5	34.4	28.1	15.6	9.4
26.CONVERSE	29	17.2	31.0	37.9	13.8	0.0	32	12.5	28.1	15.6	37.5	6.3
27.HEARTBEAT	29	10.3	34.5	37.9	17.2	0.0	32	12.5	28.1	21.9	31.3	6.3
28.EARPHONE	29	13.8	27.6	34.5	20.7	3.4	32	12.5	28.1	37.5	18.8	3.1
29.SOFTSOUND	29	17.2	24.1	34.5	24.1	0.0	32	12.5	31.3	37.5	15.6	3.1
40.PEEP	28	28.6	14.3	28.6	14.3	14.3	32	15.6	28.1	15.6	31.3	9.4
41.BOTTLE	28	25.0	21.4	25.0	14.3	14.3	32	15.6	28.1	31.3	15.6	9.4
42.RIFLE	28	39.3	3.6	7.1	32.1	17.9	32	40.6	25.0	6.3	18.8	9.4
43.TELESCOPE	28	32.1	7.1	14.3	28.6	17.9	32	31.3	28.1	12.5	15.6	12.5
44.CAMERA	28	32.1	14.3	7.1	32.1	14.3	32	45.2	19.4	3.2	19.4	12.9
45.NEEDLE	28	28.6	17.9	21.4	17.9	14.3	32	38.7	16.1	19.4	16.1	9.7
46.MICROSCOE	28	28.6	14.3	10.7	32.1	14.3	32	34.4	21.9	15.6	15.6	12.5

Exploratory factor analysis (EFA)

As the second step, exploratory factor analysis (EFA) was conducted using BICPACK (Hunter, 1991). The principal axis analysis with VARIMAX rotation produced 10 orthogonal factors (7 handedness factors and 3 other laterality factors) with eigenvalue greater than 1. Table 7 shows the items included in each factor and their factor loadings. These factors accounted for 67% of the variance in lateral preference (Factor 1 accounted for 19% of the variance; Factor 2 for 12%; Factor 3 for 9%; Factor 4 for 5%; Factor 5 for 4%; Factor 6 for 5%; Factor 7 for 4%; Factor 8 for 3%; Factor 9 for 3%; Factor 10 for 3%). This EFA result generally supported the *a priori* clusters except for Factor 1, which included both *a priori* Clusters 1 and 2. Items 30 (flip a coin), 34 (offer), 35 (phone), 36 (snap fingers), 39 (saltshaker), 68 (hold a heavy object: heavy), and 71 (perform any task requiring strength: strength) were found to be relocated in different handedness factors from the original *a priori* clusters. Two handedness items, 23 (bounce a basketball) and 24 (catch a baseball) were found in the footedness factor.

The problem items found in EFA were reexamined with the results of Blind Confirmatory Factor Analysis based on the results of EFA. Homogeneity of contents was checked, along with internal and external consistency of each factor yielded in EFA. Items 35 (phone), 36 (snap fingers), and 59 (hold an open umbrella) were found to correlate similarly with several factors but not to correlate highly with any single factor. Based on the content of the items, their factor loadings, and their item-factor correlations, it became evident that items 34 (offer) and 39 (saltshaker) should be returned to the original cluster (Factor 4 in EFA). In consideration of the homogeneity of item contents, it also was evident that items 68 (heavy) and 71 (strength) should be relocated in Factor 6. Finally, factor loading and item-factor correlation indicated that item 30 (flip a coin) should be moved to Factor 1 (see Table 7).

Confirmatory factor analysis (CFA)

After comparing and synthesizing the results from these preliminary analyses, five handedness items (items 23, 24, 35, 36, and 59) were dropped because they were found not to have pure characteristics of a specific factor. Finally, a factor structure consisting of 9 handedness factors and 3 other laterality factors was predetermined and then tested and validated by CFA. By direct examination, homogeneity of item contents, internal consistency within factors, and external consistency (parallelism) were examined again in CFA. Each of the final factors was homogeneous in content, satisfied the product rule internally, and was parallel in its relationship with other factors. The reliabilities (the standard score coefficient alpha) of each factor ranged from .80 to .99. The final factor structure, the items included in each factor, and the item-factor correlations are shown in Table 8. The frequency distributions of responses of each factor for right- and left-handers are shown in Figure 3.

Hierarchical Factor Analysis

The primary factor analysis produced 9 handedness factors and 3 other laterality factors. At a superficial level, this suggests that handedness is multifactorial and that there is no general handedness factor. However, the 9 handedness factors themselves were inter-correlated (range .33-.90), with each factor correlated moderately to highly (range .57-.90) with at least one other factor. The correlations between the primary factors are shown in Table 9.

The classic hierarchical factor model has two levels : (a) a multidimensional primary factor level in which the basic items are found to have multiple clusters and (b) a one-dimensional primary factor correlation pattern. That is, if the classic hierarchical model were to fit these data, then the correlations in Table 9 should fit a one-factor model. This was tested by applying exploratory and confirmatory factor

Table 7

Principal Axis Analysis with Varimax Rotation Matrix for the Laterality Items

Item	Factor Loading(×100)									
	1	2	3	4	5	6	7	8	9	10
1. WRITE	88*	19	16	5	-3	10	9	9	-13	9
2. DRAW	88*	19	17	6	-1	9	9	10	-13	9
6. SEW	81*	19	15	15	13	15	10	3	7	13
5. SPOON	76*	22	18	19	13	17	5	6	-5	13
19. DART	75*	28	11	3	13	15	12	16	34	6
18. BOWLING	75*	24	12	-3	11	20	15	13	36	7
7. HAMMER	74*	21	16	15	15	14	9	10	17	15
21. PINGPONG	74*	26	19	12	11	11	13	5	24	13
20. VOLLEY	73*	19	12	-1	12	16	17	13	37	10
4. TOOTHBRUSH	73*	22	13	20	13	17	9	-3	-9	14
22. TENNIS	72*	26	18	5	11	10	12	8	35	8
10. ERASER	71*	22	21	21	9	9	9	15	-15	13
8. KNIFE	69*	13	15	26	14	11	14	2	10	15
16. THROW	68*	30	14	-3	9	20	15	13	39	10
3. SCISSORS	67*	12	10	21	22	15	7	9	6	9
17. SHOOT	65*	30	14	13	25	10	11	16	26	10
9. SCREWDRIVER	65*	19	14	25	25	11	12	15	10	16
25. FRISBEE	53*	23	15	14	17	14	14	18	30	11
30. FLIPCOIN	50*	32	13	18	24	13	18	17	23	8
39. SALTSHAKER	46*	36	17	38	7	17	9	19	3	11
71. STRENGTH	43*	28	15	8	15	39	14	39	23	7
35. PHONE	36*	24	12	35	12	6	12	21	15	9
54. CLIP	22	80*	10	9	10	9	18	12	7	4
52. DIME	22	77*	13	12	13	10	14	15	6	5
50. MARBLE	24	75*	11	15	13	13	7	18	12	7
56. PIN	31	74*	13	8	11	13	18	14	15	5
53. PBACKBOOK	19	72*	11	20	16	15	7	4	-2	10
47. PAPER	22	71*	16	30	13	9	8	4	2	5
48. WALLET	19	69*	11	27	17	13	8	5	-2	8
51. JAR	21	69*	9	19	16	21	8	13	5	11
49. BASEBALL	30	67*	7	4	13	15	7	17	19	1
55. GLASS	33	57*	11	18	15	22	4	7	-1	11
34. OFFER	21	45*	13	43	20	23	12	-1	5	5
36. SNAPFINGER	10	26*	2	21	14	9	13	6	10	0
43. TELESCOPE	19	8	87*	11	6	6	6	6	4	7
46. MICROSCOPE	19	11	86*	8	8	5	9	6	3	7
40. PEEP	5	13	86*	5	9	10	14	7	5	3
41. BOTTLE	10	15	85*	8	9	10	13	4	3	3
45. NEEDLE	21	12	83*	4	11	9	10	8	3	4
44. CAMERA	26	13	82*	9	8	5	12	6	7	6
42. RIFLE	27	-7	81*	8	6	6	2	2	6	8

(Table Continued)

Table 7. (Cont'd)

Item	Factor Loading(×100)									
	1	2	3	4	5	6	7	8	9	10
37. SWITCH	11	32	8	60*	7	11	10	15	5	4
38. DOORBELL	16	35	14	58*	7	13	15	12	7	2
32. POINT	29	39	10	53*	15	13	13	9	4	7
33. KNOCK	34	31	14	52*	17	15	16	13	21	8
31. WAVE	27	36	14	51*	18	14	10	12	11	1
14. HOP	10	21	7	14	67*	4	17	6	2	1
15. BALANCE	20	17	13	-5	54*	13	23	7	-1	4
13. TOE	24	32	12	16	53*	11	14	4	5	-5
12. STEPSTOOL	19	30	20	21	48*	15	9	13	-1	-2
11. KICK	28	17	7	9	41*	17	9	19	24	7
23. BASKETBALL	23	26	12	28	40*	20	7	13	19	7
24. CATCHBALL	26	24	20	17	32*	25	15	12	7	8
60. BUCKET	25	24	10	20	13	76*	18	7	8	14
61. CARRYSCASE	28	27	12	15	14	76*	17	11	8	11
58. CARRYBCASE	31	30	16	14	16	67*	14	15	7	10
68. HEAVY	31	34	12	14	15	60*	12	25	13	6
57. PICKSCASE	39	28	18	9	16	55*	15	16	18	12
59. UMBRELLA	17	23	13	22	23	28*	21	-2	1	13
26. CONVERSE	20	13	11	10	12	12	73*	6	6	1
27. HEATBEAT	17	17	15	13	15	11	71*	11	7	3
29. SOFTSOUND	16	12	14	9	15	9	70*	9	3	1
28. EARPHONE	15	21	18	15	17	15	63*	4	7	3
69. JARCAP	17	25	16	9	14	16	10	71*	10	-1
70. BOTTLETOP	26	27	10	21	14	15	12	69*	8	9
67. OPENCAN	27	27	7	24	9	13	13	58*	2	8
65. BAT	34	10	10	19	5	10	6	7	59*	5
66. AXE	43	12	11	17	7	19	10	9	56*	9
63. BROOM	29	10	10	2	5	10	4	4	0	86*
64. MOP	31	14	10	6	2	11	3	5	5	86*
62. SPADE	38	12	13	10	1	16	1	4	13	63*

Table 8

Item-Factor Correlation Matrix

Second-order Factor	Primary Factor	Item	Factor 1	2	3	4	5	6	7	8	9	10	11	12	r*
FACTOR I VERY SKILLED	Factor 1 (write-draw)	1.WRITE	99	85	77	46	48	52	49	54	44	42	36	38	98
		2.DRAW	99	85	77	46	48	52	49	54	45	43	36	39	98
FACTOR II SKILLED	Factor 2 (use-manipulate)	6.SEW	81	90	82	56	51	59	54	61	45	52	42	39	80
		5.SPOON	79	88	75	52	49	60	55	60	47	52	37	42	78
		7.HAMMER	70	86	84	55	51	59	56	62	51	53	42	40	74
		4.TOOTHBRUSH	72	84	70	43	47	57	53	57	40	48	38	36	71
		9.SCREWDRIVER	62	83	76	52	48	62	56	59	55	59	45	38	70
		8.KNIFE	65	82	73	50	48	59	47	55	43	48	42	38	67
		10.ERASER	80	79	69	42	47	60	53	54	51	49	39	43	62
		3.SCISSORS	63	78	71	46	41	55	47	55	46	53	37	32	61
	Factor 3 (throw-shoot)	19.DART	75	81	94	60	46	60	59	66	55	56	43	36	89
		18.BOWLING	72	81	92	62	46	55	56	67	52	54	45	37	85
		16.THROW	68	75	91	60	48	57	59	67	52	53	45	38	82
		20.VOLLEY	70	79	90	61	48	52	51	64	50	53	45	37	80
		22.TENNIS	69	80	88	64	45	56	57	60	49	51	43	41	78
		21.PINGPONG	73	84	86	59	50	61	58	61	49	52	44	39	74
		17.SHOOT	66	79	86	56	45	64	62	62	55	63	44	39	74
		25.FRISBEE	53	69	74	53	41	57	53	59	52	51	43	37	55
		30.FLIPCOIN	54	68	74	47	39	63	61	61	54	59	48	36	54
	Factor 4 (bat-axe)	65.BAT	36	46	53	86	26	40	34	41	34	34	27	24	75
		66.AXE	44	57	63	86	35	46	41	54	41	42	35	29	75
	Factor 5 (mop)	64.MOP	43	49	45	32	97	36	35	41	29	26	21	26	93
		63.BROOM	40	46	41	26	91	30	29	36	25	24	18	24	82
		62.SPADE	43	53	51	35	73	37	35	45	31	25	20	29	54
FACTOR III LESS SKILLED	Factor 6 (point-touch)	33.KNOCK	44	59	62	51	35	81	59	58	52	57	46	35	65
		32.POINT	41	56	52	36	31	80	63	53	48	53	41	30	64
		31.WAVE	38	53	53	36	26	76	60	53	50	53	40	33	58
		38.DOORBELL	32	43	42	33	22	74	56	45	45	45	39	31	55
		39.SALTSHAKER	58	68	64	43	41	72	64	60	57	52	39	39	51
		34.OFFER	34	50	48	32	28	72	65	57	41	55	41	32	52
		37.SWITCH	26	37	34	29	21	66	51	41	45	39	33	23	44
	Factor 7 (pick-up)	50.MARBLE	40	51	57	40	32	67	86	58	57	57	39	31	74
		54.CLIP	41	48	54	36	28	64	85	55	52	56	44	30	72
		52.DIME	40	50	54	35	29	65	84	56	55	58	42	32	71
		56.PIN	48	56	63	44	33	67	84	61	56	58	46	34	71
		47.PAPER	40	52	51	33	29	71	82	52	47	53	38	35	67
		51.JAR	35	51	52	35	34	66	82	61	52	55	40	29	67
		53.PBACKBOOK	36	48	47	30	32	64	81	53	46	52	36	30	66
		48.WALLET	35	48	47	28	30	67	79	53	48	53	38	30	63
		49.BASEBALL	41	50	62	39	28	59	77	56	53	53	37	27	59
		55.GLASS	45	58	54	35	35	62	73	58	48	50	35	31	54
	Factor 8 (strength /lift)	61.CARRYSCASE	43	55	58	42	39	58	56	90	50	55	47	33	81
		58.CARRYBCASE	46	58	60	43	40	62	60	87	54	57	46	37	76
		60.BUCKET	38	54	53	41	40	59	54	86	48	51	46	31	74
		68.HEAVY	44	57	61	44	35	62	62	85	61	57	45	34	73
		57.PICKSCASE	51	62	67	52	44	58	58	83	55	58	47	40	68
		71.STRENGTH	53	63	72	55	38	58	60	75	71	56	46	37	56
	Factor 9 (strength /twist-turn)	70.BOTTLETOP	40	50	53	39	31	57	54	58	90	49	39	29	80
		69.JARCAP	31	39	45	34	19	46	48	53	81	44	35	31	66
		67.OPENCAN	38	48	48	34	28	55	51	52	71	44	37	25	51

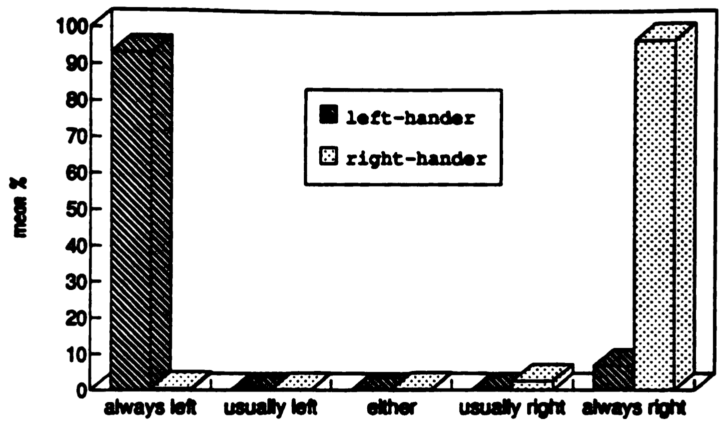
(Table Continued)

Table 8. (Cont'd)

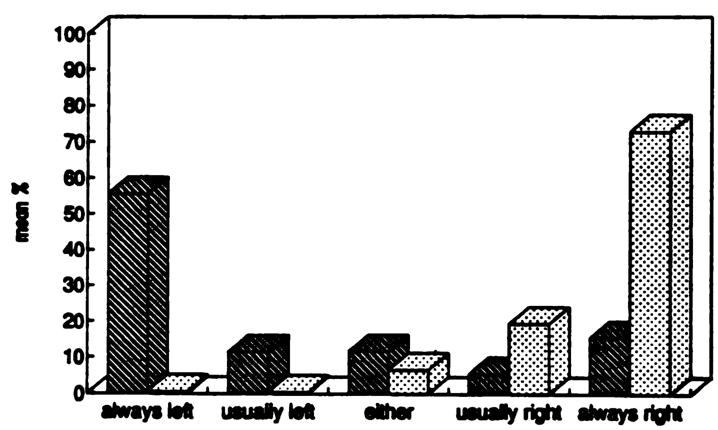
Second-order Factor	Primary Factor	Item	1	2	3	4	5	6	7	8	9	10	11	12	r*
FACTOR IV OTHER LATERALITY	Factor 10 (foot)	14.HOP	20	32	32	24	14	41	40	34	33	75	39	21	56
		13.TOE	34	45	46	30	16	53	52	46	36	74	40	29	54
		12.STEPSTOOL	30	44	42	25	18	54	52	48	44	68	37	36	46
		15.BALANCE	28	38	37	26	19	33	37	40	31	60	42	28	37
		11.KICK	31	47	54	41	28	45	42	50	43	55	35	25	30
	Factor 11 (ear)	27.HEARTBEAT	29	39	43	26	20	44	40	44	39	47	81	33	66
		26.CONVERSE	29	39	41	29	17	40	36	42	34	43	79	28	63
		29.SOFTSOUND	27	35	37	25	15	38	33	39	35	44	77	30	60
		28.EARPHONE	27	38	41	31	19	45	42	46	35	48	74	34	54
	Factor 12 (eye)	43.TELESCOPE	35	41	39	27	29	38	32	36	31	35	32	92	84
		46.MICROSCOPE	34	42	39	28	28	38	34	37	31	37	36	91	82
		44.CAMERA	40	47	47	30	30	42	37	39	34	38	39	89	79
		45.NEEDLE	36	43	42	26	26	39	35	40	33	40	36	88	77
		41.BOTTLE	29	35	34	25	22	38	35	37	30	38	37	87	75
		40.PEEP	25	30	31	23	21	34	32	34	31	35	36	86	75
		42.RIFLE	40	45	43	30	31	36	31	36	29	34	29	85	73
Standard Score Coefficient Alpha			99	95	96	85	90	90	95	94	85	80	86	96	

*Item reliability

Factor 1



Factor 2



Factor 3

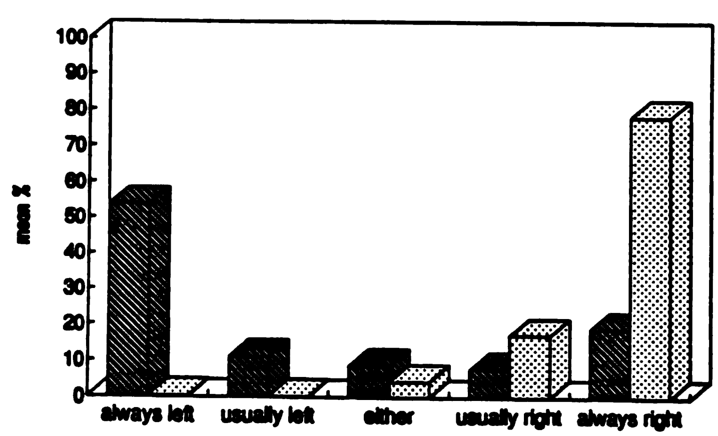
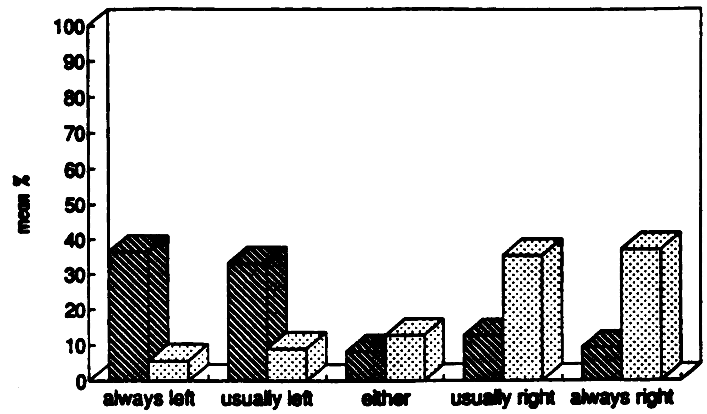
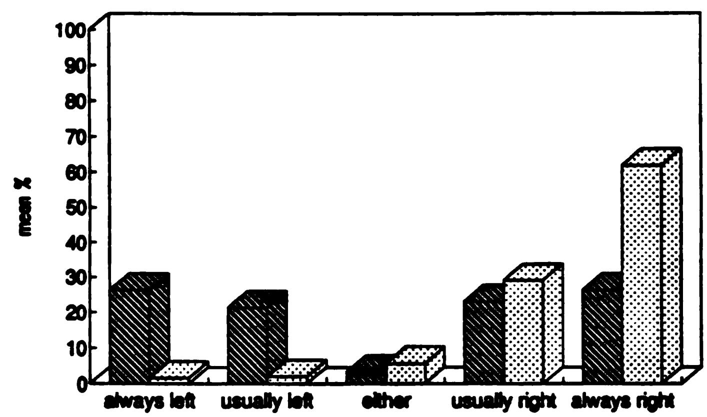


Figure 3. The distributions of left, either, and right responses for the activities represented by Factors 1 to 12 in the self-classified right-handers and left-handers.

Factor 4



Factor 5



Factor 6

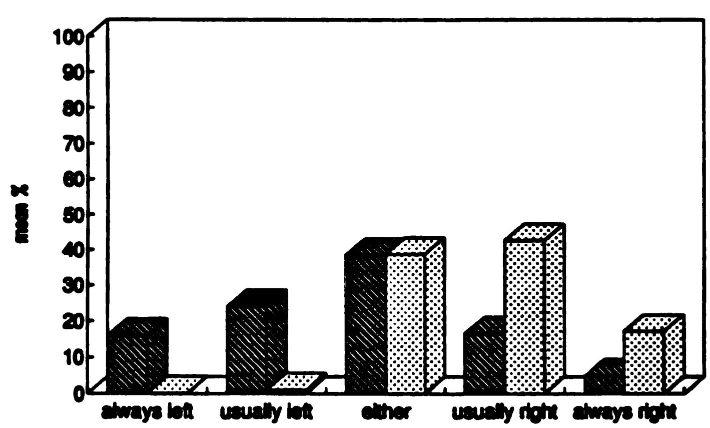
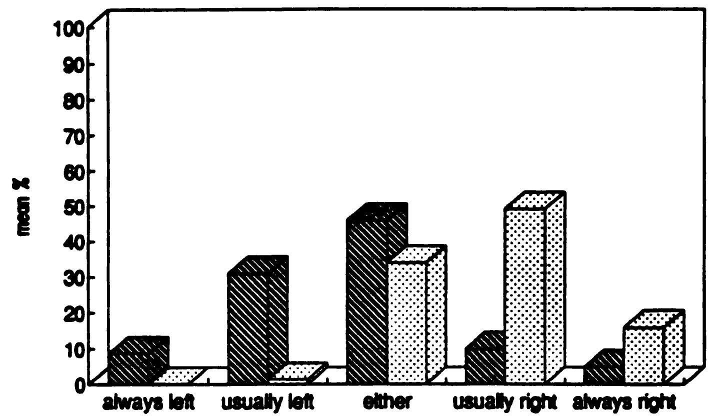
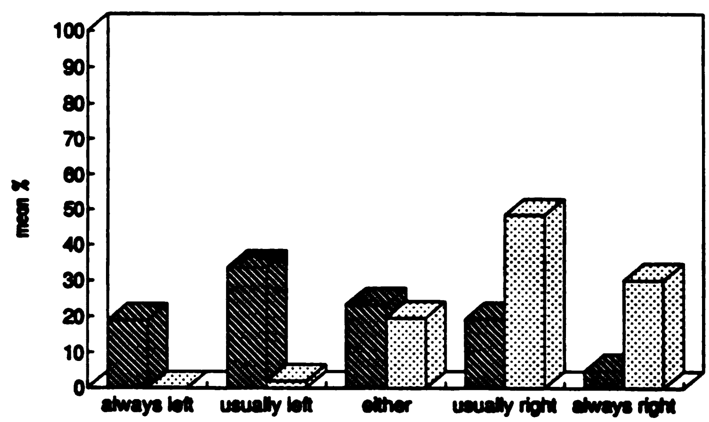


Figure 3. (Cont'd)

Factor 7



Factor 8



Factor 9

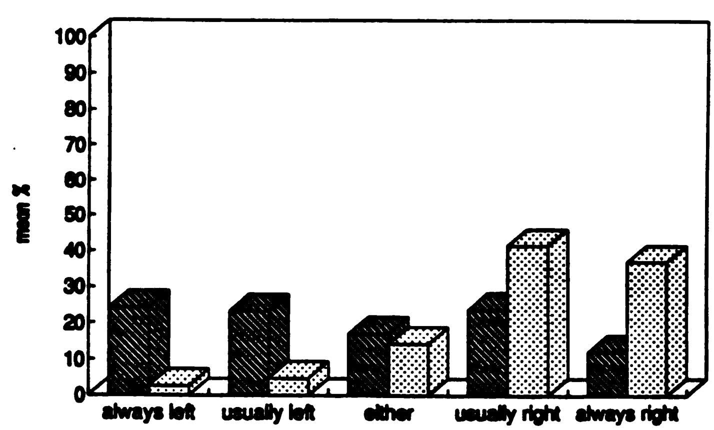
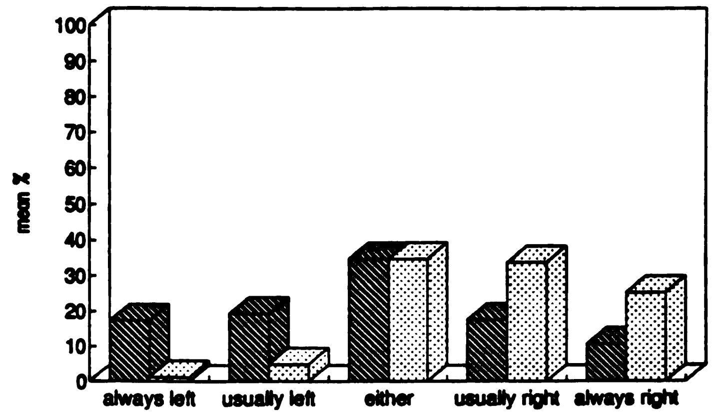
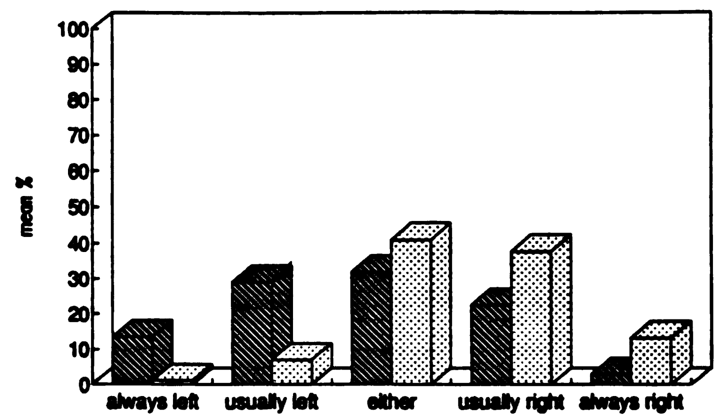


Figure 3. (Cont'd)

Factor 10



Factor 11



Factor 12

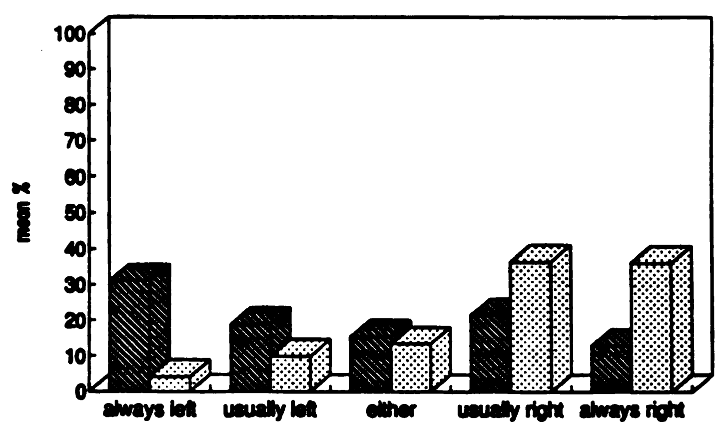


Figure 3. (Cont'd)

analysis (the second-order EFA and CFA) to the 12-factor correlation matrix in Table 9.

The principal axis analysis with VARIMAX rotation produced 2 factors with eigenvalue greater than 0.5.[6] The second-order FACTOR I included 5 primary handedness factors (Factors 1, 2, 3, 4, and 5) and accounted for 29% of the variance. The second-order FACTOR II included 4 primary handedness factors (Factors 6, 7, 8, and 9) and 3 other laterality factors (Factors 10, 11, and 12) and accounted for 34% of the variance.

Based on the results of the second-order EFA, a hierarchical factor structure consisting of 4 second-order factors was determined for the second-order CFA. FACTOR I included only the primary Factor 1 (write-draw). FACTOR II included the primary Factors 2 (use-manipulate), 3 (throw-shoot), 4 (bat-axe), and 5 (mop). FACTOR III included the primary Factors 6 (point-touch), 7 (pick-up), 8 (strength/lift), and 9 (strength/turn-twist). Separate from other handedness factors, FACTOR IV included the primary Factors 10 (footedness), 11 (earedness), and 12 (eyedness). The reliabilities of each second-order factor were 1.00, .86, .91, .72, respectively. In consideration of the nature of the primary factors comprising each of these four secondary factors, the names "very skilled," "skilled," "less skilled," and "other laterality" were chosen for the four, respectively (see Table 8). Factor loadings and second-order factor intercorrelations are shown in Table 10.

The second-order factor analysis produced three handedness factors

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[6] A variety of rules have been applied for deciding when to stop factoring (e.g., Kaiser's rule, maximum likelihood factor analysis, scree test). The most popular stop rule is Kaiser's eigen rule: "Stop when the eigenvalue goes below 1.00." However, it has been found that although Kaiser's rule works well on large correlation matrices, it works poorly if the number of variables is smaller than 50 and it causes serious problems when the number of variables is smaller than 25 (Hunter, 1988). In the case of the hierarchical factor analysis of the present study, the number of variables was 12 because there were 12 primary factors. Therefore, an eigenvalue of 0.5 instead of 1.0 was chosen for this second-order EFA.

Table 9

Factor-Factor Correlation Matrix

	1	2	3	4	5	6	7	8	9	10	11	12
Factor 1	100	85	78	46	48	52	49	54	45	43	36	39
Factor 2	85	100	90	59	57	70	63	69	56	62	48	46
Factor 3	78	90	100	67	53	68	67	73	60	63	52	44
Factor 4	46	59	67	100	36	50	43	55	44	44	36	30
Factor 5	48	57	53	36	100	39	38	47	33	28	23	43
Factor 6	52	70	68	50	39	100	80	71	65	68	54	31
Factor 7	49	63	67	43	38	80	100	69	63	67	49	38
Factor 8	54	69	73	55	47	71	69	100	67	66	55	42
Factor 9	45	56	60	44	33	65	63	67	100	57	46	35
Factor 10	43	62	63	44	28	68	67	66	57	100	58	42
Factor 11	36	48	52	36	23	54	49	55	46	58	100	40
Factor 12	39	46	44	31	30	43	38	42	35	42	40	100

Table 10

Factor Loadings and Second-Order Factor Intercorrelations

	FACTOR I	FACTOR II	FACTOR III	FACTOR IV
Factor 1	100	82	60	57
Factor 2	85	93	78	76
Factor 3	78	96	81	77
Factor 4	46	66	58	54
Factor 5	48	57	47	39
Factor 6	52	73	88	80
Factor 7	49	67	86	75
Factor 8	54	78	83	79
Factor 9	45	62	76	67
Factor 10	43	63	78	77
Factor 11	36	51	61	74
Factor 12	39	48	47	55
FACTOR I	100	82	60	57
FACTOR II	82	100	84	79
FACTOR III	60	84	100	90
FACTOR IV	57	79	90	100

and one factor encompassing the other laterality factors. Once again, this would suggest that handedness is multifactorial and is separate from other laterality factors. However, Table 10 shows that the second-order factors were also highly correlated with each other, ranging form .57 to .90. Thus a third-order factor structure needs to be considered.

The third-order analysis can proceed in two directions. First, the high correlations between the three second-order handedness factors (i.e., $r = .84, .82, .60$) points to a single general factor for handedness (Table 11). Furthermore, because FACTOR III is correlated .90 with a factor based on the other three measures of laterality, that is, primary factors 10 (footedness), 11 (earedness), and 12 (eyedness) (see Table 10), it is clear that the data fit a model with one general laterality factor. This analysis can be considered a fourth-order factor analysis. It will be presented in the next section.

Second, there is a question of the deviations of the handedness correlations from a linear hierarchical model. The hypothesis of a nonlinear measurement model was tested in several ways. As a test for nonlinearity, scatterplots of the relations between second-order handedness factors were formed. These are presented in Figure 4. Fitting a least square line to the data in the scatterplots yielded the residual plots against the predicted values. If the assumptions of linearity and homogeneity of variance are met, there should be no relationship between the predicted and residual values and the residual would be randomly distributed in a band about the horizontal straight line through 0 by the nature of the least square procedure (Myers, 1990). Systematic patterns between the predicted values and residuals shown in Figure 4(A) and (C) strongly suggest violations of the linearity assumption. Figure 4(B) also shows the violations of the homogeneity of variance. Figure 5 also presents nonlinear regression analyses of the relationships between handedness second-order factors. These results suggest that the general handedness factor could be

Table 11

<u>The Correlations Between the Second-Order Handedness Factors and the Third-Order Confirmatory Factor Analysis</u>

CONFIRMATORY FACTOR ANALYSIS (COMMUNALITIES IN THE DIAGONAL)

		1	2	3	F
FACTOR I	1	62	82	60	78
FACTOR II	2	82	103	84	103
FACTOR III	3	60	84	65	80
GENERAL FACTOR	F	78	103	80	100

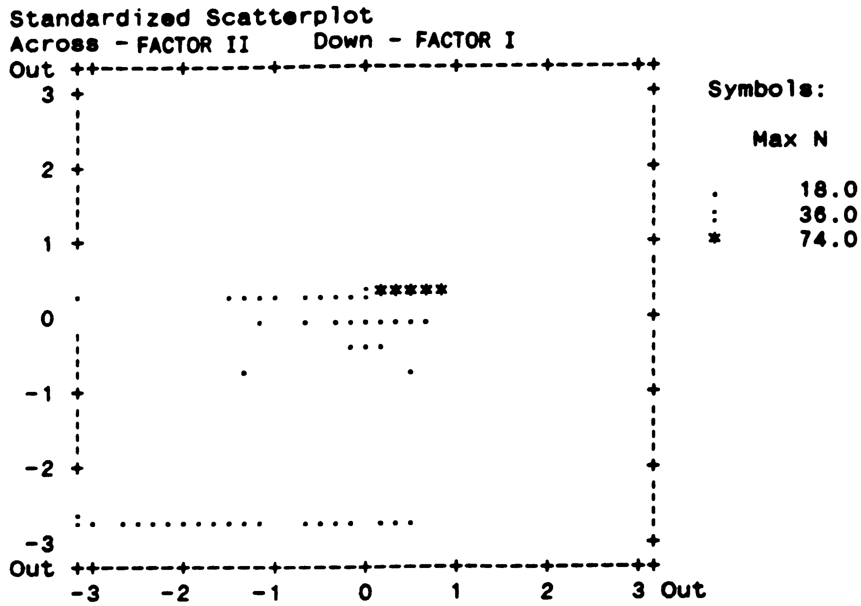
Table 12

<u>The Key Findings on General Laterality: Correlations Between Third-Order Laterality Factors and the Fourth-Order Confirmatory Factor Analysis</u>

CONFIRMATORY FACTOR ANALYSIS (COMMUNALITIES IN THE DIAGONAL)

		1	2	3	4	F
Hand	1	80	75	59	51	90
Foot	2	75	67	58	42	82
Ear	3	59	58	48	40	69
Eye	4	51	42	40	31	55
General Factor	F	90	82	69	55	100

(A) FACTOR I vs. FACTOR II



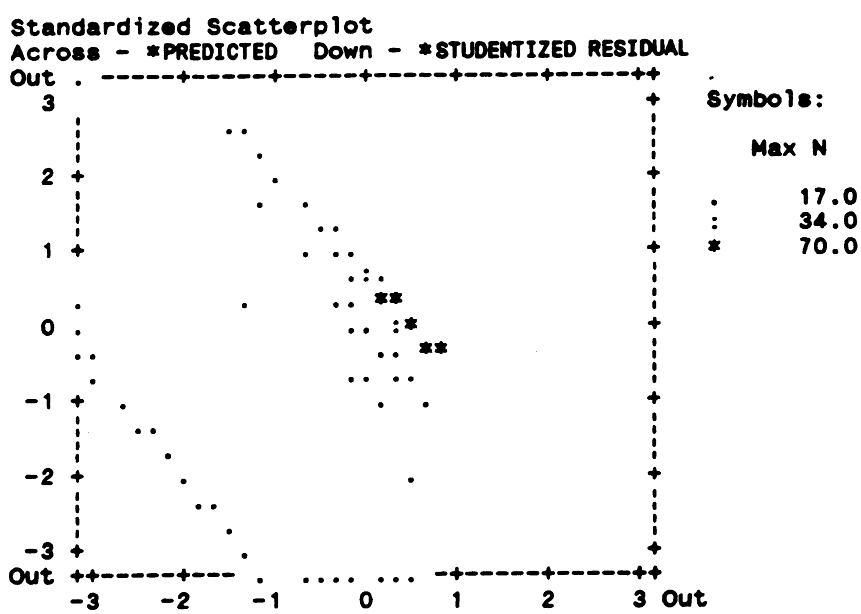
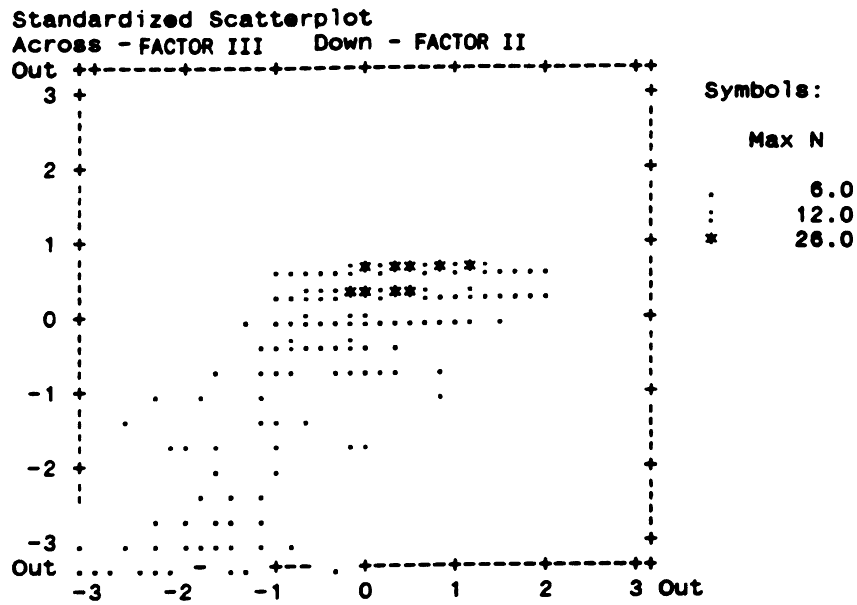


Figure 4. Standardized scatterplots between handedness second-order factors and the residual plots.

(B) FACTOR II vs. FACTOR III



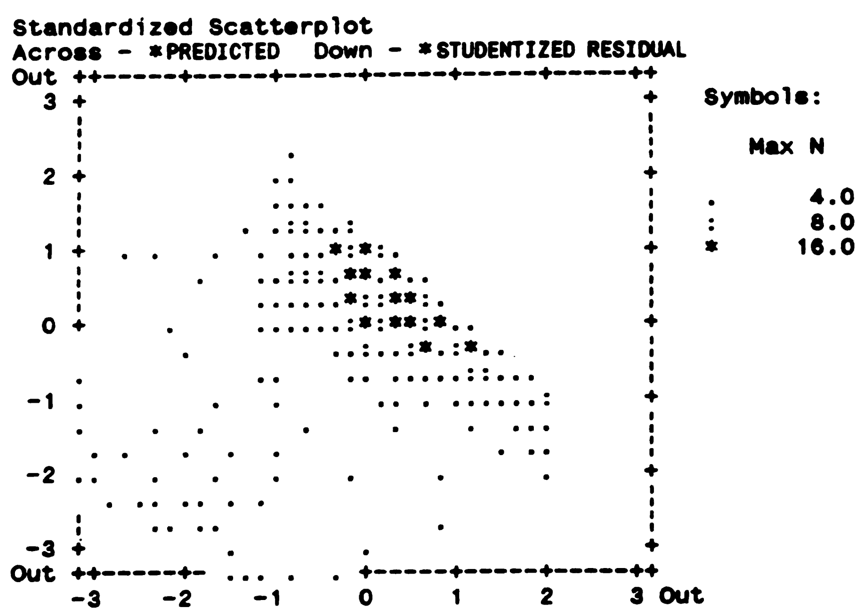
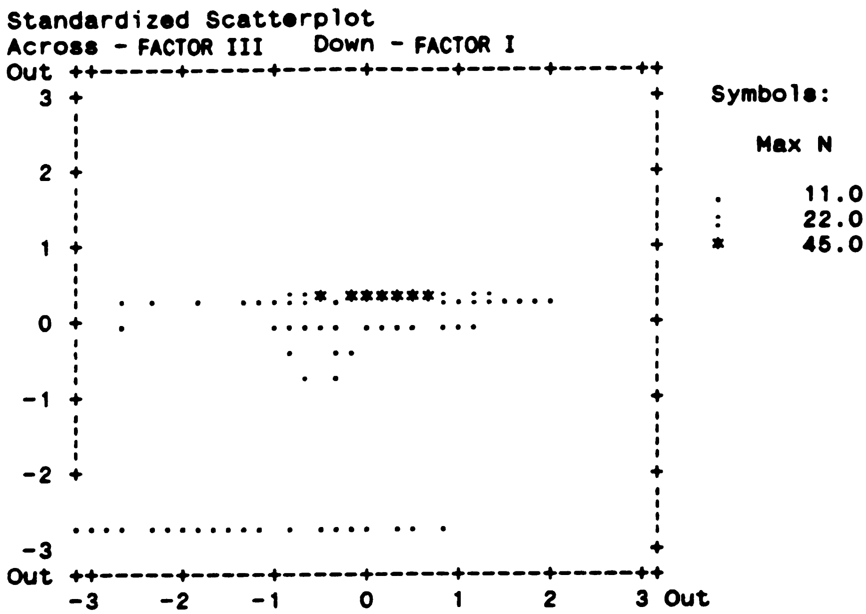


Figure 4. (Cont'd)

(C) FACTOR I vs. FACTOR III



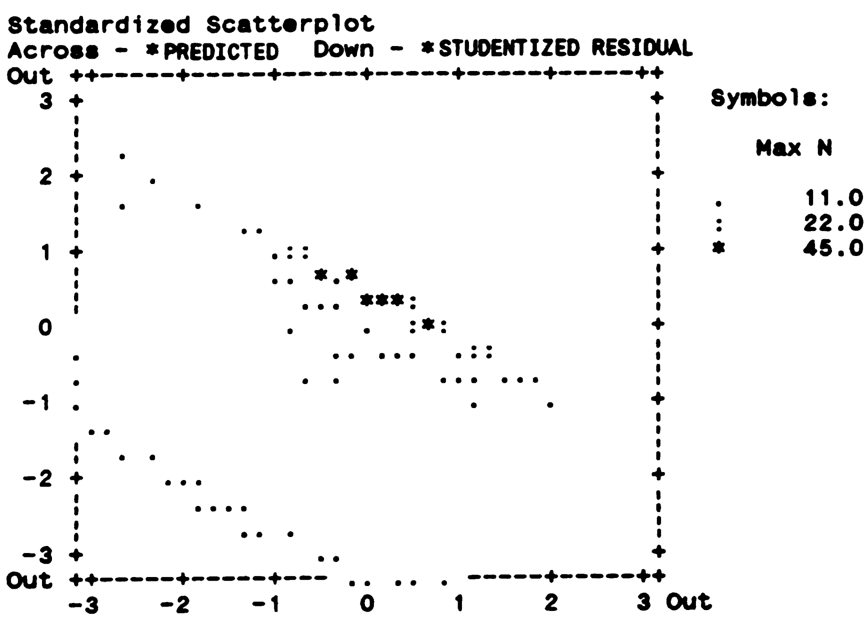


Figure 4. (Cont'd)

(A) FACTOR I vs. FACTOR II

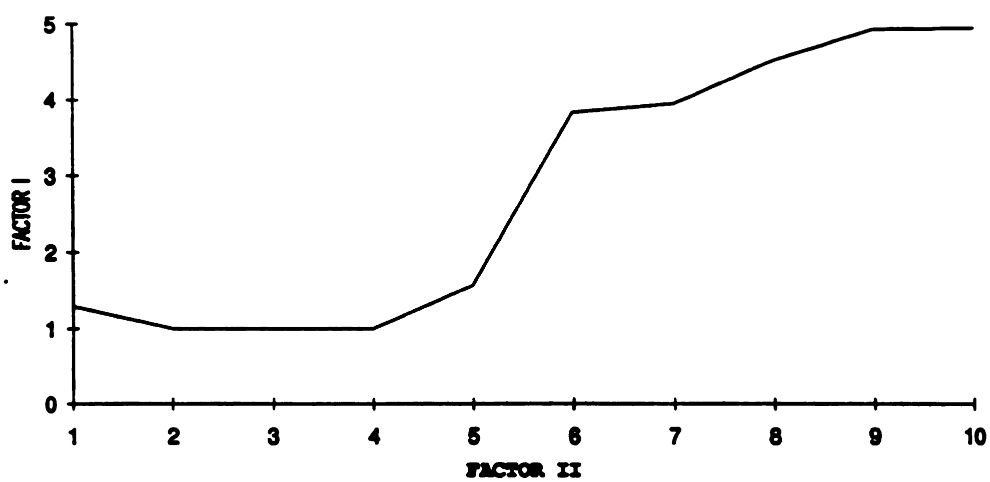
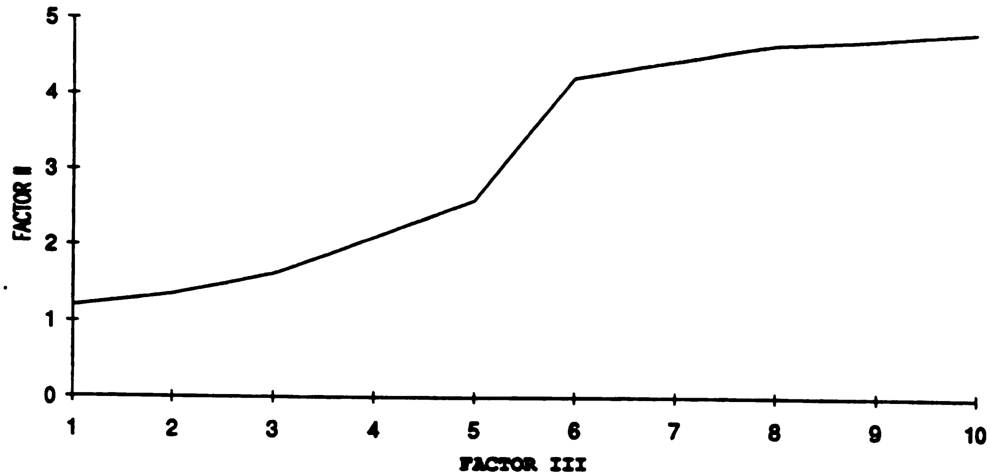


Figure 5. Relationships between handedness second-order factors. Y axis: Mean handedness score (range: 1 [always left] - 5 [always right]). X axis: Mean handedness score (range: 1 [always left] - 5 [always right]) Category number: 1 (1.00-1.40); 2 (1.41-1.80); 3 (1.81-2.20); 4 (2.21-2.60); 5 (2.61-3.00); 6 (3.01-3.40); 7 (3.41-3.80); 8 (3.81- 4.20); 9 (4.21-4.60); 10 (4.61-5.00).

(B) FACTOR II vs. FACTOR III



(C) FACTOR I vs. FACTOR III

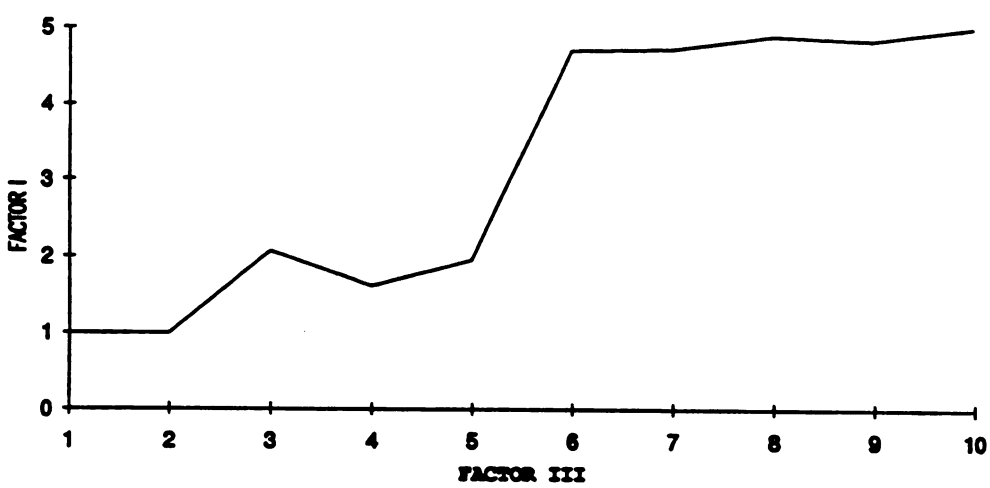


Figure 5. (Cont'd)

nonlinearly related to the second-order factors.

The General Laterality Factor

The results revealed high correlations between the three second-order handedness factors and the factor determined by the other lateralities. This suggests that a general factor underlies all aspects of laterality.

One overall handedness factor was formed by applying confirmatory factor analysis to generate one factor from the 9 primary handedness factors. That is, a confirmatory factor analysis was performed on the correlations in Table 9 in which one handedness factor was formed and the other three laterality factors were kept unchanged. The resulting 4 × 4 laterality correlation matrix is presented in Table 12. Confirmatory factor analysis showed that the correlations almost perfectly fit a one-factor model ($\chi^2(6) = .27$, ns).

The loadings of the specific laterality factors onto the general laterality factor are also shown in Table 12. The correlations between general laterality and specific laterality were .90 for handedness, .82 for footedness, .69 for earedness, and .55 for eyedness. These results therefore suggest that handedness is an almost perfect indicator of general laterality.

Discussion

The results of the hierarchical factor analysis indicated that the 50 handedness items used in CFA did not constitute a single simple handedness factor. Rather the structure proved to be hierarchical and in part nonlinear. Consider, first, the finding that the structure was hierarchical. Just as there are specific factors that distinguish each modality preference factor from the general laterality factor, so too are there specific factors that distinguish one primary handedness factor from other factors. Furthermore, handedness did not satisfy the classical two-level hierarchy but rather showed a three-level hierarchy consisting of 9 primary factors, 3 second-order factors, and 1 general

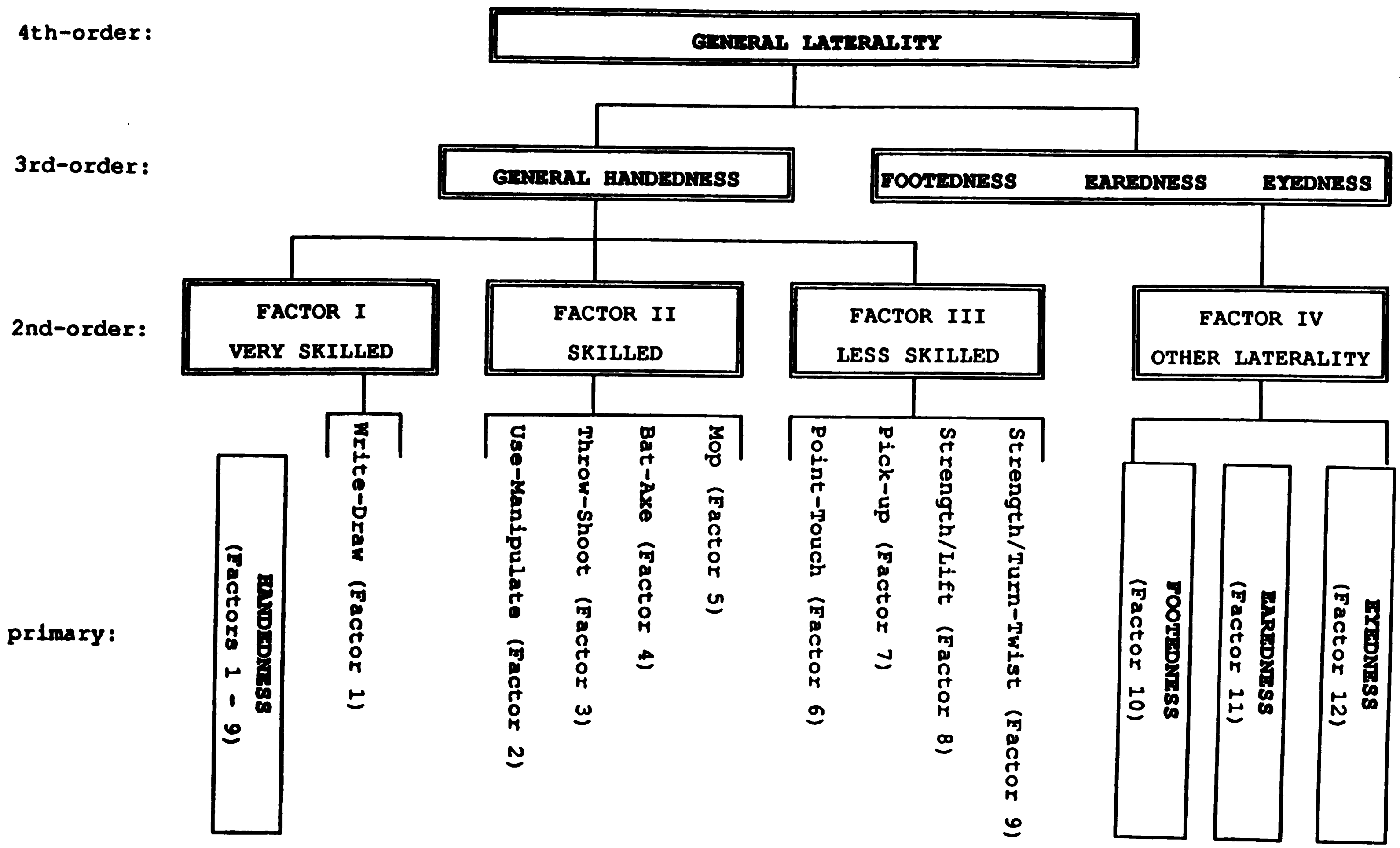


Figure 6. The hierarchical structure of human laterality.

handedness factor (see Figure 6).

The large clusters of hand-preference items that define the second-order factors differ from each other in the amount of skill required to carry out those acts. One interpretation of the nonlinear relations between these second-order factors is that flexibility in hand use varies with skill. For simple acts, there is little loss in using the non-preferred hand. This allows nearly complete flexibility in use of the non-preferred hand. Peters (1990a) has argued that this flexibility is determined by the distinction between "activities that matter" and "those that do not matter." For example, if we pick up a piece of paper from the table, it does not matter which hand is used because there is no cost in using the non-preferred hand. Hand preference for these less skilled simple acts (i.e., acts that offer flexibility in use) correlates highly ($r = .90$) with FACTOR IV ("other laterality"). For acts that require more skill, this flexibility of use is reduced, and the correlation to the "other laterality" factor is reduced as well. Thus, the correlation between the "skilled" handedness factor and the "other laterality" factor is .79. For the "very skilled" handedness factor, which consists of the acts of writing and drawing, the data showed virtually no flexibility. Instead, the scores were sharply bimodal showing that for these skills there was essentially no variation in the hand used. The correlation between the "very skilled" handedness factor and the "other laterality" factor is only .57.

Within levels of skill, the primary factors were highly correlated with each other but were nonetheless distinct. Thus within skill levels there must be specific factors that distinguish one primary factor from another. Many investigators have interpreted the results of exploratory factor analysis to mean that the structure of handedness is multifactorial. This has led to considerable discussion and disagreement in the literature about which specific factors distinguish one primary factor from another. This literature will be discussed below. However, it need only be pointed out here that many of the disagreements are built on the mistaken premise, that a multifactorial structure, based on EFA, means that the handedness primary factors are independent dimensions. The high correlations between primary factors within skill levels indicate that the second-order factors are stronger than the specific factors in determining preference.

The characteristics of primary factors.

a. "Very skilled" behaviors (FACTOR I). FACTOR I included only the primary Factor 1. Primary Factor 1 (write-draw) consisted of two items, writing and drawing, that are highly overlearned, "very" skill-demanding tasks, requiring delicate distal movements of the fingers. Most subjects (95%) claimed to "always" use their dominant hand for these tasks. However, it has been observed that the preferred hand for writing is not necessarily the one preferred for other manipulative tasks (Annett, 1972). Writing is a didactically trained behavior in the sense that it is strongly influenced by social or cultural pressures. Throughout the literate world, the right hand has been the hand routinely trained for writing and drawing. In the present study, 6.7% of the self-classified left-handers reported that they always use their right hand for writing and drawing. For this reason, some researchers have argued that writing should not be used alone to predict cerebral specialization for manual praxis or speech.

b. "Skilled" behaviors (FACTOR II). FACTOR II included the primary Factors 2 (use-manipulate), 3 (throw-shoot), 4 (bat-axe), and 5 (mop). These primary factors showed the gradient in size of the specific factors (see Table 10) that distinguish one primary factor from another within a second-order factor. Factor 2 (use-manipulate) included skilled activities that use or manipulate tools such as a screwdriver, knife, hammer, or scissors. These activities require the movement of fine distal musculature and continuous modification of a motor program as a consequence of the prior movement's effect on the environment (Healey et al., 1986). Of the 439 self-classified right-handers, 72.9% reported "always" using their right hand for these activities, whereas only 1.1% reported "always" using their left hand. By contrast 55.7% of the 61 self-classified left-handers reported "always" using their left hand, and 21.1% reported "always" or "usually" using their right hand, with 15.6% reporting "always." In contrast to writing and drawing, these activities are <u>less</u> subject to explicit social pressures. However, there are several tools (e.g., screwdriver, scissors) that could be described as intrinsically right-biased. In using these tools, left-handers therefore might be disposed to use their right hand for the sake of convenience.

Factor 3 (throw-shoot) consisted of activities that involve the precision throwing or shooting of projectiles, for example, throwing a ball or a dart at a target, "serving" a volleyball. These acts, especially throwing a ball, require a ballistic application of force from whole body movement (whole arm moving from shoulder joint) in combination with fine manipulative skill in handling the object to be thrown (distal musculature). Of the right-handers, 78.1% reported they used their dominant (right) hand exclusively for these activities, whereas only 0.5% reported using their non-dominant (left) hand. By contrast, only 53.8% of the left-handers reported exclusive dominant-(left-) hand use, 26.7% non-dominant (right) hand use.

The activities of Factor 3 were usually found in the same factor with the activities of Factors 1 and 2 in most previous studies (e.g., Bryden, 1977; Payne, 1987; Steenhuis & Bryden, 1989). Throwing behaviors (throwing a ball or a dart, shooting a basketball) have characteristics in common with the activities in Factors 1 and 2. Throwing at a target is a highly skilled acts. Much like writing or sewing, its success requires the execution of a complex sequence of motor behaviors. The results showed that these throwing behaviors were highly lateralized similar to the activities in Factor 2 (see Figure 3).

This finding is consistent with Steenhuis and Bryden's (1989) suggestion that neural mechanisms controlling the chaining of complex motor sequences are more effective when one hemisphere is specialized for that control. The EFA in the present study also yielded one factor that included both Factors 2 and 3. Factors 2 and 3 also were highly intercorrelated ($r = .90$).

In spite of these several characteristics that suggest a factor in common, throwing behaviors (Factor 3) were separated from other unimanual skilled behaviors (Factor 2) in the present study for the following reason. Acts included in Factor 3 were under primary control of proximal/axial musculature unlike those in Factor 2, which were under the control of fine distal musculature. Some researchers (e.g., Beukelaar & Kroonenberg, 1983; Healey et al., 1986) who found a separate factor for acts of throwing, as was the case in the current study, have suggested that the kind of musculature involved in the activities could provide useful information about hand preference. Recent studies (e.g., Peters & Servos, 1989; Snyder & Harris, 1992) have found that a significant number of left-handers (the "inconsistent" left-handers) show a dissociation in the hand chosen for fine manual skill and the hand chosen for strength and ballistic activities, such as throwing. This suggests that although this left-handed subtype probably would not significantly influence the factor structure in a representative sample, meaning one with an appropriately small percentage of left-handers (like the current sample), it might affect the structure, namely, by yielding a separate factor for acts of throwing, if the proportion of left-handers was larger. That would suggest that at least where left-handers are concerned, the distal/proximal dimension is not a negligible factor for skilled behaviors. Therefore, it is expected that the separation of Factor 3 and Factor 2 may provide interesting information about handedness, especially for left-handers.

Factor 4 (bat-axe) contained two bimanual items, bat and axe.

Like Factor 3, it is also a proximal/axial movement factor that involves an axial or whole body movement. Healey et al. (1986) emphasized that activities in Factor 4 were less ballistic in nature and required more strength and less accuracy than throwing behaviors. However, these also are skilled behaviors that can improve with practice (hitting a baseball also requires considerable precision and skill). Like Steenhuis and Bryden's (1989) study, which found that most subjects (about 70%) gave strongly lateralized responses for the 2 activities comprising the "bat and axe" factor, the current finding that most right-handers (91%) used their dominant hand for these activities also suggests the high level of skill required for these behaviors. By contrast, only half (51.7%) of the left-handers reported that they used their left (dominant) hand for these activities, and half reported using their right hand. In other words, half of the left-handers preferred to swing bats and axes over their right shoulder. This result supports Peters and Servos' (1989) finding that a significant number of left-handers show a dissociation in hand preference for fine manual skill and hand preference for strength and proximal behaviors. It also suggests that although these activities, bat and axe, require a certain level of skill, the strength or distal/proximal dimension is the more important factor for these activities, at least where left-handers are concerned.

Factor 5 (mop) consisted of activities calling for sweeping and shoveling movements performed with both hands, involving turning of the spine and use of the back muscles, and performed with stick-like equipment (Beukelaar & Kroonenberg, 1983) such as a broom, mop, or spade. Sweeping and shoveling require gross limb movements rather than fine hand and finger control. Raczkowski et al. (1974) found relatively poor agreement (.78) between the questionnaire response and a performance test on the broom item. Bryden (1977) suggested that because such activities are performed infrequently (he presumably meant for certain populations such as contemporary college students), r

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respondents may find it hard to imagine the situation clearly enough to make a reliable assessment of their hand preference. Another possibility is that the wording of the question itself contributes to these inconsistencies. For questions such as "Which hand do you place above the other when using a shovel?" (Provins et al., 1982) or "Which hand is higher when using a spade?" (Beukelaar & Kroonenberg, 1983), the meaning of "above" or "higher" may be unclear. To avoid any possible confusion in the current study, the three questions of the form, "Which hand is closer to the end when using ... ?," were accompanied by a drawing of the object with a mark identifying the "end" (see Appendix A, p. 159). Although the results disclosed a marked decrease in exclusive use of the dominant hand in both right-handers (37.3%) and left-handers (36.6%) and an increase in use of the non-dominant hand (14.6% for right-handers, 21.9% for left-handers), the large majority of right-handers (72.7%) and left-handers (69.9%) still reported dominant-hand use.

c. "Less skilled" behaviors (FACTOR III). FACTOR III included the primary Factors 6 (point-touch), 7 (pick-up), 8 (strength/lift) and 9 (strength/turn-twist). These primary factors were highly correlated with each other and showed the uniformity in size of the specific factors (see Table 10). Both Factors 6 and 7 consisted of less skilled, unimanual, and distal behaviors, with 10 items comprising each *a priori* cluster. The results disclosed separate factors for the activities of Factor 6 and Factor 7. Factor 6 (point-touch) consisted of relatively easy tasks, such as knocking at the door, waving goodbye, and switching on the light. These tasks generally are performed with a stiff wrist and do not require very much specific (or detailed) movements of the individual fingers or complex coordination of the trunk, arm, and hand (Beukelaar & Kroonenberg, 1983). Instead, they require only simple movements of the hand and/or the upper arm. For these tasks, the exclusive use of the dominant hand decreased markedly for both right-

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(17.2%) and left-handers (16.0%), while "either" responses increased (to about 40% for right- and left-handers alike).

Factor 7 (pick-up) consisted of the acts of picking-up small objects ranging in size from a pin or paperclip to a glass of water. Along with the activities in Factor 6, these activities presumably are minimally influenced by social or cultural pressure. Like Factor 6, there was a marked increase in "either" response for these activities (33.7% for right-handers, 45.7% for left-handers). This weak lateralization suggests that there may be no need for a highly specialized motor sequence for reaching for and grasping an object. On the average, only 15.8% of right-handers and 13.6% of left-handers reported that they used one hand exclusively, but not necessarily the "dominant" hand, for these activities. Steenhuis and Bryden (1989) reported that although subjects showed an increase in "either" response for picking-up behaviors, they still used their normally preferred hand. The present study found this to be so for the right-handers but not for the left-handers. That is, whereas the majority of the right-handers (64.8%) used their right hand for picking up a small object, the left-handers reported more "either hand" use (45.7%) than left-hand use (39.5%). This result does not support the MacNeilage et al. (1987) argument that in primates, the right hand is preferred for manipulating of objects, the left hand for grasping objects. It is consistent, however, with Harris and Carlson's (1988) finding that the lateral position of target objects in reaching tasks influences adult subjects' hand choice, such that more reaches are made with the same-side hand whether or not it is the preferred hand.

The current study also showed that object size influences hand preference. Factor 7 consisted of 5 items (picking up a marble, clip, dime, pin, and paper) requiring a "pincer grip" (thumb and forefinger opposed) and 5 items (picking up a jar, paperback book, wallet, baseball, and glass) requiring a "palmer grip" (whole hand grip). Among t

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the right-handers, 67.6% preferred their right hand for objects requiring a pincer grip, whereas 41.7% of the left-handers preferred their left hand use ($\chi^2(1)=78.59$, $p<.001$). For objects requiring a palmer grip, 62.2% of the right-handers and 38.4% of the left-handers preferred their dominant hand ($\chi^2(1)=63.14$, $p<.001$). The right-handers also preferred their dominant hand more often for objects requiring a pincer grip than for those requiring a palmer grip ($\chi^2(1)=14.08$, $p<.001$), whereas the left-handers did not show any differences of hand choice ($\chi^2(1)=0.68$, ns). When the males and the females among the right-handers, however, were considered separately, this difference was found only in the males ($\chi^2(1)=15.82$, $p<.001$). Harris and Carlson (1988), using a performance task, also found that when the target object is located in the subject's midline, object size also influences hand choice but in different ways for right- and left-handers. Both right- and left-handers reached more often with their preferred hand (on more than 75% of the trials) for objects requiring a pincer grip. However, for objects requiring a palmer grip, only 58% of the right-handers reached with the preferred (right) hand, whereas 88% of the left-handers reached with the preferred (left) hand. Although the current study and Harris and Carlson's study showed somewhat different results, both studies suggest that, depending on object size, different neural mechanisms might be controlling the act of reaching, even when the same "distal" movements are involved.

Although visually-directed reaching has long been used in primate studies to find hand preference at the species level (Ogle, 1871, cited in Harris, 1992b), usually it has been used as a handedness measure only in human infant research on the assumption, as Harris and Carlson (1992) point out, that for adults, a simple reaching task does not make sufficient demands on manual praxis. However, it has been noted that these activities are minimally influenced by social or cultural pressure. Several recent studies have reported the usefulness of these activities as a measure of handedness. Dean, Schwartz, and Smith (1981) reported that among 3 handedness factors, learning-disabled children showed significantly more bilaterality or mixed dominance, in comparison to normal children, only on a factor involving "visually guided fine motor activities," which included both activities of Factors 6 and 7 in the present study. Steenhuis and Bryden (1989) argued that, in comparison to well-lateralized skilled activities, preference for less lateralized activities was better related to cortical organization of functions like language.

Both Factor 8 (strength/lift) and Factor 9 (strength/turn-twist) consisted of tasks requiring <u>high</u> manual strength more than fine motor dexterity. Factor 8 consisted of activities requiring heavy lifting or carrying and involved a proximal or a whole body movement, for example, carrying a heavy suitcase, whereas Factor 9 consisted of more distal activities that require turning of the wrist and upper body (hand-arm) strength, such as opening a can of soda and unscrewing a tight jar cap. Although both factors showed an increase in "either" response (21.3% for Factor 8, 15.6% for Factor 9), about 80% of right-handers and 50% of left-handers reported that they used their dominant hand for these activities. Peters (1990a) found that slightly less than half of left-handers (47%) showed a stable dissociation between the writing hand and the hand used for strength activities. In the current study, about 30% of the left-handers reported a right-hand preference for strength activities, 20% reported "either hand" use, and 50% preferred left hand preference. The existence of a separate hand strength factor has been suggested by several researchers (e.g., Healey et al., 1986; Steenhuis & Bryden, 1989), although no such factor was found in their studies. Only Dean (1978a) found a hand strength factor that included both proximal behaviors (Factor 9 in the present study) and distal behaviors (Factor 8 in the present study). These two separate hand strength factors suggest that the distal/proximal dimension is one of the important dimensions of the handedness factor structure, although all factors cannot be classified as merely "distal" or "proximal."

d. "Other laterality" (FACTOR IV). Separate from other handedness factors, FACTOR IV included the primary Factors 10 (footedness), 11 (earedness), and 12 (eyedness). The footedness factor (Factor 10) consisted of 5 items such as kicking, stepping on a stool, picking up a pebble with a toe, hopping, and balancing. About 60% of self-classified right-handers reported that they preferred their right foot for these activities, 6.3% their left foot, and 34.7% either foot. By contrast, 36.8% of left-handers preferred their left foot, 28.4% their right foot, and 34.8% either foot. The left-handers thus showed an increase in preference of the foot on the opposite side as their dominant hand.

It has been consistently found (Annett & Turner, 1974; Porac & Coren, 1981; Searleman, 1980) that handedness and footedness are related more to each other than to any of the measures of sensory laterality. Physiological considerations suggest that although hands and feet may share a similar control locus in the contralateral cerebral hemisphere, such a clearly lateralized control system does not exist for ears and eyes (Porac et al., 1980). Observation of motor deficits after pyramidal tract lesions suggests that the relation of the foot to the leg is comparable to that of the hand to the arm. According to Brodal (1973), during recovery from complete paralysis of the left side after a right-sided stroke, arm and leg movement (proximal musculature) was possible, but finger extension was not, and dorsiflexion of the toes was lost altogether. In this sense, the specific motor innervation of hands and feet seems to be quite similar.

The assessment of footedness in human beings is complicated by the interactions between hand and foot. Although foot roles are determined by the role of the hands in many activities as in the stance taken when throwing a ball, foot preference evidently does not relate in any simple way to hand preference. Thus, Peters (1988) found that footedness follows handedness in right-handers but not in left-handers. In right-handers, who showed a right-foot bias for activities requiring fine manipulation and focused attention, the right leg also tended to be shorter and lighter, whereas the left leg, which played a support role, tended to be longer and heavier. Left-handers, however, expressed this functional preference less clearly.

A major problem in determining the relationship between handedness and footedness is that proper measures of footedness have never been theoretically justified or agreed upon. Previc (1991) argued that the correlation between handedness and footedness may be extremely high if the footedness measure properly distinguishes between flexion and extension activities. Unambiguous measures of voluntary flexion activity (e.g., kicking, writing on sand) showed high correlations between handedness and footedness, whereas measures that assessed extension (e.g., standing on one foot, stepping on a stool) correlated poorly with the other measure of footedness. Previc's arguments, however, are not supported by the present data, which failed to find consistent high or low correlations between either flexion or extension activities and handedness measures.

The earedness factor (Factor 11) consisted of 4 items pertaining to ear preference in situations where both ears cannot be used simultaneously, such as listening to the radio through a single earphone and listening to someone's heartbeat. These items showed a marked increase in "either" or "usually" responses. For these activities, only 14.4% of the right-handers and 16.5% of the left-handers reported that they exclusively used a particular ear, not necessarily the same side ear as their dominant hand. Of the right-handers, 51% reported that they preferred their right ear for these activities, 8% their left ear, and 41% either ear. Of the left-handers, 42.6% reported their left-ear preference, 25.4% right-ear preference, and 32% either ear.

The eyedness factor (Factor 12) included 7 items that measured sighting preference (Coren & Kaplan, 1973) such as looking through a telescope and threading a needle. For these activities, 72.6% of the right-handers reported that they preferred to use their right eye, 14% their left eye, and 13.4% either eye. Of the left-handers, only 50% reported left-eye preference, 34.4% right-eye preference, and 15.6% either eye.

Auditory information from both ears is also bilaterally available at all stages of processing beyond the superior olive. Similarly, visual information from the two eyes is available to both hemispheres, since there is only partial decussation of the optic fibers at the chiasm. Therefore some investigators (e.g., Coren & Kaplan, 1973; Porac & Coren, 1976) have argued that ear and eye preference may be under the control of other mechanisms that need not be correlated to hemispheric asymmetries, whereas laterality of limbs may reflect the involvement of the speech-dominant cerebral hemisphere.

If there are different causal mechanisms for ear or eye, why are many people not only right-handed and right-footed but also right-eared and right-eyed as shown in the present study? How can we explain the significant correlation between hand and ear or hand and eye? Because both eyes project equally to both hemispheres and because there appears to be no anatomical basis for a hemisphere-eye association, there seems to be no intrinsic sensory difference that could explain why one eye is preferred. New electrophysiological data, however, imply hemispheric control of the contralateral eye (Seyal, Sato, White, & Porter, 1981). Money (1972) also found evidence supporting Walls' (1951) suggestion that sighting dominance depends on asymmetries of motor function. It is reasonable to suppose that the control of the several pairs of muscles involved in eye movement and fixation would demand a high level of skill. If the control system for one eye is more efficient than that for the other eye, the more efficient eye is likely to be preferred for activities requiring the use of one eye. The greater skill in controlling one eye thus might be analogous to the greater skill in controlling one hand (Porac & Coren, 1976).

The frequency distributions of right, either, and left responses of footedness, earedness, and eyedness are also shown in Figure 3.

Hierarchical factor analysis. The hierarchical factor analysis results showed that the large clusters of preferences that define the second-order factors differ from each other in the amount of skill required to carry out those activities. This finding is consistent with Steenhuis and Bryden's (1987, 1989, 1990) suggestion that the skill required to perform a manual task is important in distinguishing handedness factors. This second-order factor structure was also supported by the degrees of laterality shown by each primary factors. Nine factors were analyzed to determine the extent to which the behaviors represented by each factor were lateralized in terms of hand preference. The mean preference scores of each factor were compared within self-classified handedness groups with a Wilcoxon Matched Pairs Signed Ranks Test. Within the right-handed group, the factors ranking from most to least rightward skewed were Factors 1, 3, 4, 2, 9, 8, 5, 7, and 6. All comparisons between the 9 mean factor scores were significant ($p<.001$) except those between Factors 9 and 8, between Factors 8 and 5, and between Factors 7 and 6. In left-handers, the factors ranking from most to least leftward skewed were Factors 1, 2, 3, 5, 8, 6, 7, 9, and 4. Differences between Factor 1 versus Factors 2, 3, or 5 and between Factors 2, 3, or 5 versus Factors 8, 6, 7, 9, or 4 were significant. However, there were no significant between-factor differences among Factors 2, 3, and 5 or among Factors 8, 6, 7, 9, and 4. These results can be expressed as follows:

Right-handers: F1 > F3 > F4 > F2 > F9 = F8 = F5 > F7 = F6.

(but F9 > F5)

Left-handers: F1 > F2 = F3 = F5 > F8 = F6 = F7 = F9 = F4.

These orders are consistent with the degree of skill required for activities in each factor. The laterality differences between Factor 1 versus Factors 2 and 3 for both right- and left-handers support the separation of the "very skilled" second-order factor from the "skilled" second-order factor. The differences between Factors 2, 3, 4, and 5 versus Factors 6, 7, 8, and 9 support the distinctiveness of the "skilled" second-order factor and the "less skilled" second-order factor. This results also support Provins et al.'s (1982) prediction that highly practiced and skilled movements will be more strongly lateralized than activities that depend on manual strength. When we recall Kimura's (1982) suggestion that a specialized left-hemisphere control system underlies the selection and execution of a sequenced motor behavior in manual praxis, it suggests that there may be no need to invoke a highly specialized motor sequencing system for simply picking up certain objects, switching on the light, lifting a heavy object, or opening a can of soda.

In addition, it is noteworthy that within FACTOR II ("skilled" second-order factor), Factor 3 involving more <u>proximal</u> musculature showed more lateralized responses than Factor 2 involving more <u>distal</u> musculature, and that within FACTOR III ("less skilled" second-order factor), Factors 8 and 9 requiring high strength showed more lateralized responses than the other less skilled primary factors (Factor 6 and 7) requiring low strength. These differences were found for right-handers, not for left-handers. These results therefore suggest that within skill levels, there must be specific factors such as distal versus proximal or the degree of strength required that distinguish one primary factor from another and these specific factors are also important for understanding human handedness.

The high level of correlations between second-order handedness factors are consistent with the assumption of a one-factor model. The factor loadings for the second-order handedness factors on the general handedness factor would be .78, 1.00, .80 respectively (Table 11). That is, this pattern would suggest that FACTOR II is a perfect measure of the general handedness factor.

Foot, ear, and eye preference are generally less subject to social training and cultural pressure than hand preference, although foot preference is undoubtedly somewhat influenced by social training as in learning athletic skills. For this reason, some researchers have proposed that these other lateralities are better indices than handedness for the study of brain lateralization. If their arguments were correct (although whether or not they are correct still remains to be seen), the assumption that FACTOR II is a perfect measure of a general handedness factor can be tested by considering the correlations between the second-order handedness factors and the factor for the other lateralities (FACTOR IV). If FACTOR II were a perfect measure of handedness and brain lateralization, then FACTOR II should have a higher correlation with the factor defined by the other lateralities. The correlations between the second-order handedness factors and FACTOR IV are .57, .79, and .90, respectively (Table 10). Thus it is not FACTOR II but FACTOR III that has the highest correlation with the factor based on the other lateralities. This would suggest that FACTOR III is the better measure of handedness and brain lateralization.

The general laterality factor. Lateral preference refers to the tendency to favor one side of the body in the performance of activities. It has long been regarded as a behavioral manifestation of brain lateralization. Although the most commonly acknowledged form of lateral preference is handedness, lateral preferences are also found for the feet, ears, and eyes (Clark, 1957; Porac & Coren, 1976, 1981). From the present study, total scores of the Lateral Preference Questionnaire, including hand, foot, ear, and eye use, showed a strongly negatively skewed distribution (see Figure 2). This suggests that there is a strongly biased tendency towards right-side preference in all combination of other lateralities as well as in handedness alone. The strongest right-side bias is for handedness (90.8%; see Table 13). The percentage of right-side preference was somewhat lower for foot use at 82.6%, lower still for eye preference at 76.9%, and lowest of all for ear preference at 66.1%.

Researchers (e.g., Annett, 1978; Levy, 1976) have presumed that there is a "primary sidedness" that determines all expressions of laterality (motor and sensory) and that "primary sidedness" is mediated by an asymmetrical neural mechanism. However, some researchers (e.g., Coren & Kaplan, 1973; Porac & Coren, 1976) have argued that human laterality may not be adequately described as a unitary dimension with a single origin. In their view, it seems unlikely that a single neural factor could account for all facets of lateral preference on anatomical grounds. Thus, visual information from the two eyes is available to both hemispheres, because there is only partial decussation of the optic fibers at the chiasm. Similarly, auditory information from both ears is bilaterally available at all stages of processing beyond the superior olive. Thus, whereas limb preference may reflect the involvement of the speech-dominant cerebral hemisphere (at least for right-handers), eye and ear preference may be under the control of other mechanisms that need not be correlated to hemispheric asymmetries. Although limb preference is primarily motoric, the sense organs have afferent rather than efferent, or motor, functions. They (e.g., Porac et al., 1980) also have argued that separation of sensory laterality into two dimensions may be a function of intrinsic differences between auditory and visual information processing, with efferent function being a clear component of eyedness but not of earedness.

Several investigators have extended the factor analysis to include footedness, earedness, and eyedness as well as handedness. Brito et al. (1989), using the 10-item Edinburgh Handedness Inventory and one item each for foot, ear, and eye preference, found 2 factors, a Motor-Related Laterality Factor, which included the hand- and foot-preference items,

Table 13

Percentage of Subjects Classified as Right-Sided for the Four Indices of Lateral Preference

Preference Type	Total Sample (N=502)	Female (*n*=250)	Male (*n*=252)
Hand	90.8	90.4	91.2
Foot	82.6	88.0	76.3***
Ear	66.1	72.0	59.0**
Eye	76.9	74.1	77.6

** p<.01 significant sex differences
*** p<.001 significant sex differences

and a Sensory-Related Laterality Factor, which consisted of the ear- and eye-preference items. Porac et al. (1980) found a 3 factor solution, that is, limb preference (including both hand- and foot-preference), ear preference, and eye preference, from a 13-item inventory consisting of 3 to 4 items each for hand, foot, ear, and eye. Dean (1978a) found 3 handedness factors, a footedness factor, an earedness factor, and an eyedness factor from a factor analysis using 49 items. Despite their differences, all of these studies thus agree that human laterality is multifactorial.

The present study, however, indicated that, like handedness itself, lateral preference is also hierarchical (see Figure 6). That is, a factor, or preference dimension, emerged for each of the four modalities -- handedness, footedness, earedness, and eyedness -- at the level of primary factor analysis. However, the factors for the 4 modalities were themselves very highly correlated (see Table 12). A one-factor model shows perfect fit to the pattern of the intermodality correlations. Thus all preferences are determined to a considerable extent by one general laterality factor. The different modalities are not determined to the same extent by that general laterality factor. The correlations between general laterality and specific lateral dimensions are .90 for handedness, .82 for footedness, .69 for earedness, and .55 for eyedness.

The highest correlation ($r = .90$) between handedness factor and general laterality factor showed that handedness is an almost perfect indicator of general laterality. Many investigators, however, have used "self-classified" handedness as a laterality index rather than a handedness factor score measured using a "comprehensive" questionnaire like the one used in this study. In the present study, the correlation between self-classified handedness and the handedness factor score was .83. Thus the correlation between self-classified handedness and general laterality is $(.83)(.90) = .747 < .90$. It supports the conviction that a quantitative method would yield a more sensitive index of laterality than subjects' subjective self-classification. As mentioned earlier, however, the problems of arbitrary cutting points for categorizing subjects based on questionnaire scores and the questions about how many and what kinds of behaviors should be asked for getting a high correlation between handedness score and general laterality still remain to be solved.

Further Analyses

Right-Handers versus Left-Handers

Results. Previously, we took note of evidence that left-handers tend to be less lateralized than right-handers. This was also the case in the current study based on visual inspection of total scores (see Figure 7). These total scores, however, do not reveal whether left-handers are less consistent in their hand preference within an activity (resulting in choice of the "usually left" rather than the "always left" response category) or whether they are less consistent in the direction of hand preference between activities.

To answer this question and to find out whether and how it bears on the factor structure of handedness, the direction and consistency of responses within- and between-items were compared across the 9 primary handedness factors (Table 14). Within-item consistency <consistency (W)> was measured by the extent to which subjects chose "always," "usually," or "either" as answers for individual items, regardless of the direction of their preferred hand.[7] Between-item consistency <consistency (B)> was measured by the number of "always" responses with

[7] For this analysis, each response was recoded as follows: "always right" or "always left" as 1, "usually right" or "usually left" as 2, and "either" as 3.

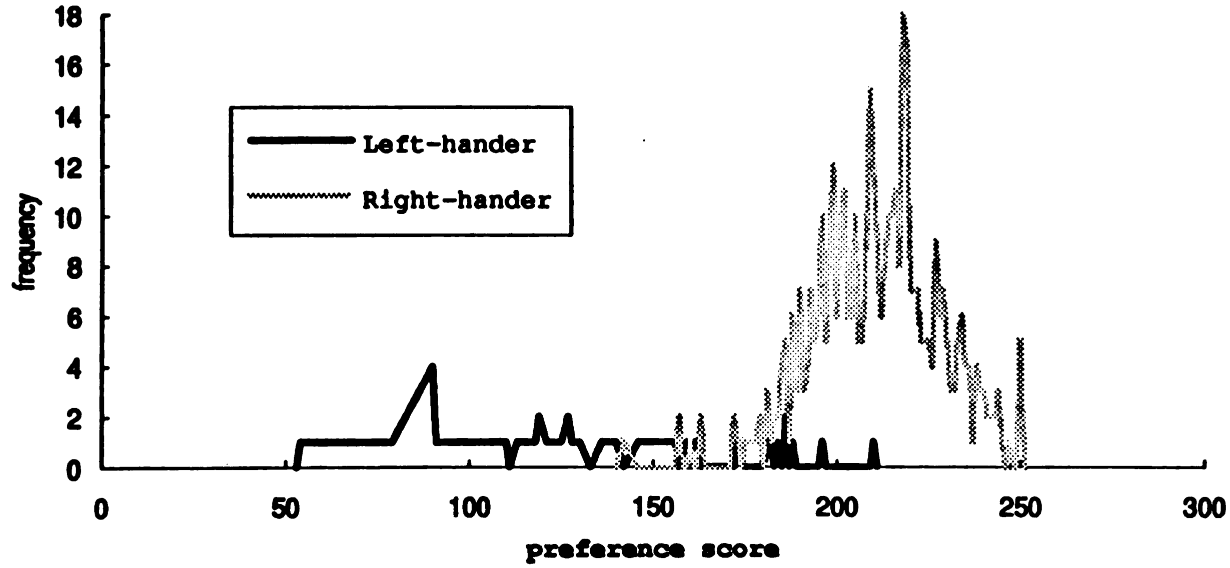

Figure 7. Frequency distributions (number of subjects) of hand preference scores of the right-handers and left-handers. Minimum score = 50 (50 items x 1); Maximum score = 250 (50 items x 5).

Table 14

Mean Preference Score (Standard Deviation) on the Laterality Factors

Factor	Total (N=500)	Right-hander (n=439)	Left-handers (n=61)
Direction and consistency (W)			
1	4.506 (1.279)	4.949 (.312)	1.267 (1.006)***
2	4.326 (.998)	4.639 (.435)	2.137 (1.112)***
3	4.425 (.976)	4.725 (.326)	2.239 (1.331)***
4	4.297 (.989)	4.476 (.727)	3.016 (1.549)***
5	3.698 (1.173)	3.901 (1.028)	2.246 (1.150)***
6	3.627 (.667)	3.756 (.531)	2.695 (.818)***
7	3.650 (.687)	3.786 (.563)	2.715 (.727)***
8	3.872 (.829)	4.060 (.600)	2.561 (.991)***
9	3.897 (.965)	4.054 (.802)	2.778 (1.272)***
10	3.653 (.735)	3.765 (.639)	2.854 (.889)***
11	3.446 (.768)	3.547 (.693)	2.721 (.893)***
12	3.749 (1.101)	3.902 (.975)	2.654 (1.342)***
Consistency (W)			
1	1.029 (.140)	1.031 (.146)	1.000 (.000)
2	1.341 (.386)	1.327 (.384)	1.404 (.357)*
3	1.271 (.303)	1.260 (.296)	1.331 (.314)
4	1.434 (.519)	1.421 (.519)	1.508 (.504)
5	1.693 (.595)	1.698 (.594)	1.623 (.579)
6	2.215 (.515)	2.218 (.511)	2.177 (.542)
7	2.199 (.540)	2.181 (.536)	2.321 (.555)*
8	1.906 (.538)	1.895 (.539)	1.989 (.509)
9	1.754 (.565)	1.742 (.558)	1.811 (.599)
10	2.081 (.533)	2.081 (.538)	2.068 (.500)
11	2.255 (.559)	2.267 (.559)	2.156 (.554)
12	1.734 (.527)	1.733 (.516)	1.705 (.573)
Consistency (B)			
1	.957 (.178)	.967 (.191)	.918 (.277)
2	.702 (.306)	.726 (.296)	.557 (.319)***
3	.748 (.273)	.779 (.242)	.545 (.355)***
4	.574 (.447)	.618 (.435)	.270 (.414)***
5	.369 (.435)	.374 (.434)	.350 (.449)
6	.169 (.272)	.173 (.277)	.143 (.235)
7	.096 (.204)	.103 (.210)	.051 (.155)
8	.281 (.353)	.296 (.359)	.183 (.298)*
9	.351 (.400)	.368 (.403)	.240 (.366)*
10	.241 (.309)	.252 (.314)	.167 (.259)*
11	.131 (.283)	.132 (.281)	.127 (.305)
12	.351 (.371)	.361 (.370)	.290 (.381)

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

respect to dominant hand use.[8] For this analysis, handedness was defined according to the subjects' self-classification. Mann-Whitney tests were used for comparisons.

When direction and consistency (W) were considered jointly, significant differences in handedness score were found between right- and left-handers across all factors ($p<.001$). However, when consistency (W) was considered alone, left-handers proved to be less lateralized than right-handers only for Factors 2 ($p<.05$) and 7 ($p<.05$), the difference being relatively weak in each case. Contrarily, when consistency (B) was considered alone, left-handers were less lateralized on 5 factors, including Factor 2 ($p<.001$), Factor 3 ($p<.001$), Factor 4 ($p<.001$), Factor 8 ($p<.05$), and Factor 9 ($p<.05$), with the difference now being relatively strong in the majority of cases.

Discussion. These results suggest that the left-handers' weaker lateralization primarily reflects between-item rather than within-item inconsistency. That is, left-handers are as strongly lateralized as right-handers on individual items but are less consistent in the direction of hand preference across items. As previously noted, Peters and Servos (1989) have suggested that there are two subgroups of nonpathological left-handers -- consistent left-handers (CLH) and inconsistent left-handers (ILH). Peters and Servos found that CLHs and ILHs did not differ in quality and speed of performance on a variety of motor tasks they did show asymmetries in opposite direction on tasks requiring hand strength and ballistic acts (throwing at a target). That is, ILHs performed like CLHs on tasks that required fine manual skills but, unlike the CLHs, threw more accurately with the right hand. Like right-handers, ILHs also showed greater right-hand than left-hand

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[8] The index of consistency (B) used in the current study was Percent Extreme Score (Leiber & Axelrod, 1981). For the left-handers, the number of 1's ("always left" response) in each factor was divided by the total number of items for each factor: for the right-handers, the number of 5's ("always right" response) was divided by the total number of items for each factor. The consistency scores ranged from 0 (no consistency) to 1 (perfect consistency).

strength. The ILHs are inconsistent only with regard to their between-task hand preference, their within-task preference being quite consistent. For these reasons, Peters and Servos argued that treating left-handers as a single group lends the faulty impression that left-handers are less lateralized. The current results, which found significant consistency (B) differences between right- and left-handers for Factors 3 (throw-shoot), 4 (bat-axe), 8 (strength/lift), and 9 (strength/turn-twist), suggest that proportionately more left-handers than right-handers use their nondominant hand for these throwing- and strength-related behaviors. Based on the evidence in their samples, Peters (1990a) and Snyder and Harris (1992a) suggested that the ILH subgroup comprises 30-50% of the population of left-handers. Among the left-handers[9] in the current study, 53.6% were classified as ILHs and 46.4% as CLHs based on the same categorization procedure used by Peters and Servos (1989). To examine the characteristics of ILHs and CLHs directly, the direction and consistency of response within- and between-items of right-handers, ILHs, and CLHs were compared across the 9 primary handedness factors (Table 15). When consistency (W) was considered alone, the ILHs proved to be less lateralized than the right-handers for Factor 2 ($p<.001$), Factor 3 ($p<.01$), Factor 7 ($p<.05$), and Factor 8 ($p<.05$), and the CLHs proved to be less lateralized only for Factor 4 ($p<.05$). The ILHs were less lateralized than the CLHs for Factor 2 ($p<.01$), Factor 3 ($p<.05$), and Factor 8 ($p<.05$). However, when consistency (B) was considered alone, the ILHs were less lateralized than the right-handers on 6 factors, including Factor 2 ($p<.001$), Factor 3 ($p<.001$), Factor 4 ($p<.001$), Factor 7 ($p<.01$), Factor 8 ($p<.001$), and Factor 9 ($p<.001$), and the CLHs were less lateralized only for Factor 4 ($p<.001$). The ILHs showed much less between-item consistency than the CLHs for Factor 2 ($p<.001$), Factor 3 ($p<.001$), Factor 6 ($p<.05$), Factor

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[9] Based on the same categorization procedure of Peters and Servos' (1989), 5 self-classified left-handers who wrote with their *right hand* were excluded from this classification.

Table 15

Mean Preference Score (Standard Deviation) of Right-Handers, CLHs, and ILHs on the Laterality Factors

Factor	Right-hander (n=439)	Left-hander (n=56) CLH (n=26)	Left-hander (n=56) ILH (n=30)
Direction and consistency (W)			
1	4.949(.312)	1.000(.000)***	1.000(.000)***
2	4.639(.435)	1.332(.348)***	2.629(.994)***
3	4.725(.326)	1.350(.450)***	3.143(1.376)***
4	4.476(.727)	2.538(1.334)***	3.567(1.617)**
5	3.901(1.028)	1.718(.665)***	2.511(1.160)***
6	3.756(.531)	2.223(.640)***	3.025(.737)***
7	3.786(.563)	2.227(.622)***	3.110(.613)***
8	4.060(.600)	2.000(.772)***	3.178(.838)***
9	4.054(.802)	2.120(1.084)***	3.400(1.176)**
10	3.765(.639)	2.264(.699)***	3.400(.739)**
11	3.547(.693)	2.163(.836)***	3.258(.658)*
12	3.902(.975)	2.033(1.097)***	3.059(1.372)**
Consistency (W)			
1	1.031(.146)	1.000(.000)	1.000(.000)
2	1.327(.384)	1.264(.265)	1.550(.372)***
3	1.260(.296)	1.222(.231)	1.448(.362)**
4	1.421(.519)	1.615(.496)*	1.417(.510)
5	1.698(.594)	1.564(.540)	1.744(.604)
6	2.218(.511)	2.120(.548)	2.202(.530)
7	2.181(.536)	2.212(.615)	2.383(.517)*
8	1.895(.539)	1.846(.527)	2.103(.433)*
9	1.742(.558)	1.693(.560)	1.900(.638)
10	2.081(.538)	1.960(.503)	2.131(.522)
11	2.267(.559)	1.971(.622)*	2.258(.457)
12	1.733(.516)	1.615(.508)	1.764(.638)
Consistency (B)			
1	.967(.191)	1.000(.000)	1.000(.000)
2	.726(.296)	.779(.233)	.408(.260)***
3	.779(.242)	.803(.195)	.293(.303)***
4	.618(.435)	.308(.449)***	.233(.388)***
5	.374(.434)	.462(.472)	.278(.421)
6	.173(.277)	.231(.292)	.076(.153)
7	.103(.210)	.112(.223)	.003(.018)**
8	.296(.359)	.295(.354)	.050(.139)***
9	.368(.403)	.397(.411)	.089(.276)***
10	.252(.314)	.292(.316)	.053(.138)***
11	.132(.281)	.279(.420)	.017(.063)*
12	.361(.370)	.473(.412)	.181(.311)**

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

7 ($p<.01$), Factor 8 ($p<.001$), and Factor 9 ($p<.001$), with the difference being relatively strong in the majority of cases. These results, which did not find significant consistency (B) differences between the right-handers and the CLHs, but did find them between the right-handers and the ILHs for the factors consisting of tasks requiring hand muscular strength (Factors 8 and 9) and ballistic acts (Factor 3), support Peters and Servos' argument about ILHs. In addition, Peters (1990a) found that ILHs also prefer the right foot for kicking, whereas CLHs prefer the left foot. This suggests that in the current study (Table 14), the significant consistency (B) difference found in Factor 10 (footedness) also reflects the existence of two subgroups of left-handers. It is confirmed by the findings (Table 15) that there are not significant consistency (B) differences between the right-handers and the CLHs, but between the right-handers and the ILHs for Factor 10 (footedness). It should be noted that no differences were found for Factor 1 (write-draw) between the right- and the left-handers (Table 14). This again supports Peters' (1990a) finding that ILHs, like CLHs, showed a very strong and specific left-hand preference for writing, in contrast to their hand preference for throwing or other activities requiring strength. It is also confirmed by the separate analyses for the CLHs and ILHs shown in Table 15.

It is conceivable that the consistency (W) and consistency (B) differences found in Factor 2 reflect the realities of left-handers living in a right-handed world. Some tools used for the sort of skilled activities comprising Factor 2 are intrinsically biased to the right. For example, a screwdriver is asymmetrical because of the direction of wrist rotation required to tighten a screw. Most scissors, likewise, are made for right-handers. For such intrinsically biased tools, left-handers therefore may well be disposed to use their right hand. If so, these activities would yield relatively weak consistency scores of both types (W and B) among left-handers as a group. Table 15 showed that there is no difference in consistency score of both types (W and B) between the CLHs and the right-handers for Factor 2. These differences were found between the ILHs and the right-handers and between the ILHs and the CLHs. These results suggest that despite the presumptive right-bias of these tasks, some left-handers (e.g., CLHs) would or could not change their hand preference and used their left hand exclusively for these activities, whereas others (e.g., ILHs) would or could. In future research with a large sample of left-handers, we could learn more about these handedness subtypes.

__Sex Differences__

Results. The present data failed to disclose evidence of significant sex difference in the prevalence of self-classified left-handedness (male 11.6%, female 12.9%; $\chi^2(1)=.20$, ns)[10]. However, the results did show that males were more likely to be left-handed than females in the sense that total scores on the handedness questionnaire were significantly greater for females than for males ($z=1.94$, $p\leq.001$; see Figure 8). When the right- and left-handers were considered separately, the sex difference was found only in the right-handers. That is, among the right-handers, females were more strongly right-handed than males ($z=2.07$, $p<.001$), but there was no sex difference among the left-handers ($z=.56$, ns).

To determine whether sex of participant was related to the factor structure of handedness, factor analyses were performed for the men and women separately. The same factor solutions emerged for both groups and these were identical to the factor structure for the total sample. The direction, and the two consistency measures -- (W) and (B) -- were

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[10] For estimating the prevalence of left-handers, there is a problem in the use of volunteer subjects from the Human Subject Pool in the Department of Psychology. The problem is that the pool contains many more females than males. Based on research by Thompson and Harris (1978) indicating that left-handers are sensitive to their "difference," Peters (1990) has suggested that left-handers may be more likely than right-handers to participate in experiments related to handedness. Therefore, it is possible that the higher percentage of female left-handers found in the current study reflects the existence of the larger female pool in combination with a "handedness volunteer" effect.

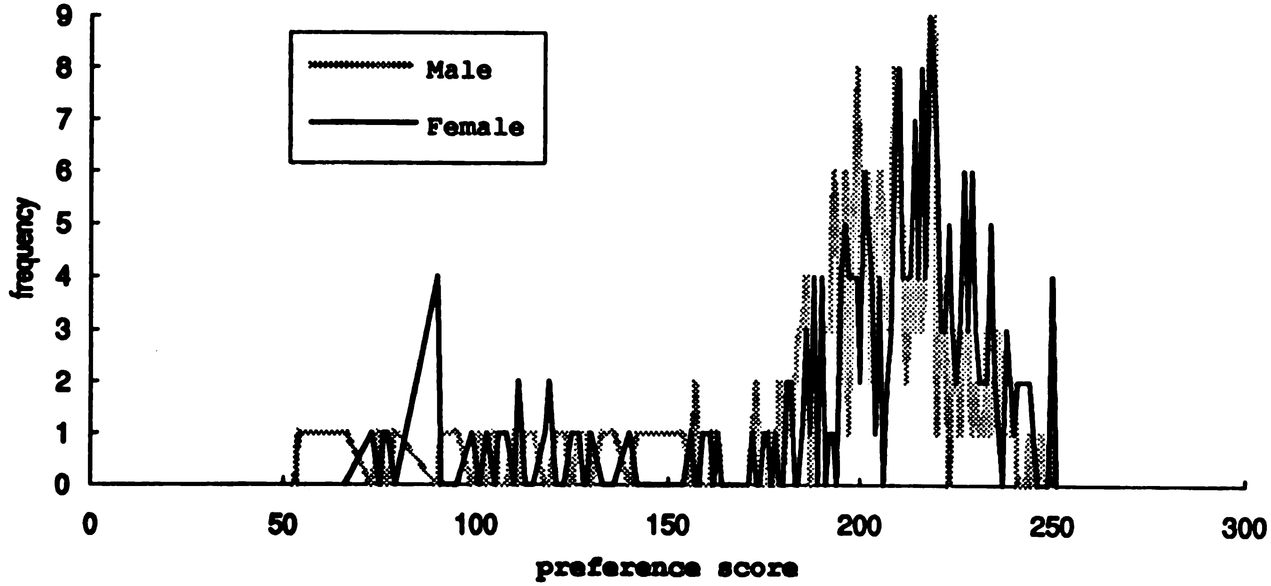

Figure 8. Frequency distributions (number of subjects) of hand preference scores of the males and females. Minimum score = 50 (50 items x 1); Maximum score = 250 (50 items x 5).

compared between males and females across the 9 primary handedness factors (see Table 16). When direction and consistency (W) were considered jointly, or when either consistency (W) or consistency (B) was considered separately, significant sex differences were found for Factors 4 (bat-axe), 8 (strength/lift), and 9 (strength/turn-twist).

Further analysis was conducted by examining the preference scores for each factor as a function of both sex and self-classified handedness (see Table 17). Although there was no sex difference for the left-handers across all factors, significant sex differences again were found for Factors 4, 8, and 9 for the right-handers. A sex difference also was found for Factor 2 for the right-handers when either direction and consistency (W) or consistency (W) was considered.

Sex differences were also examined by handedness categorization using scores on handedness questionnaire (see Table 18). Again, sex differences were found for Factors 4, 8, and 9. That is, based on the influence of the activities in Factors 4, 8 and 9, more right-handers were found among females then among males.

Individual item comparisons were conducted by computing the mean preference score of each item for males and females. It was also found that most items included in Factors 4, 8, and 9 showed sex differences. Specifically, scissors ($p<.01$) and screwdriver ($p<.01$) in Factor 2, bat ($p<.01$) and axe ($p<.01$) in Factor 4, glass ($p< .05$) in Factor 7, heavy ($p<.05$), carrybcase ($p<.05$), bucket ($p<.05$), and carryscase ($p<.05$) in Factor 8, and opencan ($p<.01$), jarcap ($p<.01$), and bottletop ($p<.01$) in Factor 9 showed significant sex differences with females being significantly more right-lateralized for all of these activities.

Discussion. As already noted, the present study found no differences in the percentage of left-handers in males versus females, presumably because of the special features of the sample (see footnote 10). It did, however, find that among the right-handers, there were sex difference in the direction and consistency of hand preference for

Table 16

Mean Preference Score (Standard Deviation) on the Laterality Factors as a Function of Sex

Factor	Male	Female
Direction and consistency (W)		
1	4.540(1.237)	4.472(1.322)
2	4.303(.967)	4.349(1.029)
3	4.329(.997)	4.459(.954)
4	4.143(1.068)	4.452(.878)**
5	3.643(1.176)	3.753(1.170)
6	3.582(.662)	3.673(.671)
7	3.606(.713)	3.693(.659)
8	3.735(.840)	4.010(.795)***
9	3.736(.936)	4.059(.967)***
10	3.552(.755)	3.753(.702)***
11	3.351(.774)	3.541(.751)*
12	3.745(1.095)	3.753(1.109)
Consistency (W)		
1	1.032(.145)	1.026(.136)
2	1.387(.407)	1.295(.359)
3	1.288(.317)	1.255(.287)
4	1.496(.526)	1.372(.505)*
5	1.728(.618)	1.657(.570)
6	2.247(.489)	2.183(.540)
7	2.218(.550)	2.180(.530)
8	2.000(.532)	1.812(.527)**
9	1.884(.575)	1.624(.525)***
10	2.135(.547)	2.028(.514)
11	2.301(.565)	2.209(.550)
12	1.735(.528)	1.733(.526)
Consistency (B)		
1	.944(.207)	.970(.142)
2	.668(.318)	.737(.290)
3	.750(.264)	.746(.281)
4	.528(.439)	.620(.452)*
5	.354(.423)	.384(.447)
6	.151(.262)	.187(.280)
7	.096(.207)	.096(.202)
8	.151(.262)	.340(.370)**
9	.270(.369)	.433(.414)***
10	.218(.306)	.263(.310)
11	.115(.261)	.147(.303)
12	.343(.361)	.359(.382)

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

Table 17

Mean Preference Score (Standard Deviation) on the Laterality Factors as a Function of Sex and Self-Classified Handedness

	Right-hander (n=439)		Left-hander (n=61)	
Factor	Male (n=222)	Female (n=217)	Male (n=29)	Female (n=32)
Direction and consistency (W)				
1	4.930 (.405)	4.968 (.170)	1.552 (1.404)	1.000 (.000)
2	4.586 (.455)*	4.692 (.408)*	2.233 (1.220)	2.051 (1.071)
3	4.703 (.347)	4.747 (.302)	2.084 (1.248)	2.389 (1.411)
4	4.342 (.804)***	4.613 (.610)***	2.638 (1.564)	3.359 (1.477)
5	3.838 (1.025)	3.966 (1.029)	2.172 (1.243)	2.313 (1.074)
6	3.714 (.502)	3.800 (.557)	2.561 (.869)	2.816 (.762)
7	3.743 (.579)	3.831 (.544)	2.638 (.802)	2.784 (.657)
8	3.929 (.606)***	4.139 (.564)***	2.356 (.932)	2.753 (1.021)
9	3.865 (.813)***	4.248 (.745)***	2.738 (1.232)	2.813 (1.325)
10	3.665 (.666)**	3.866 (.597)**	2.674 (.860)	3.006 (.898)
11	3.446 (.716)*	3.651 (.655)*	2.621 (.834)	2.813 (.948)
12	3.870 (.992)	3.934 (.959)	2.806 (1.387)	2.516 (1.308)
Consistency (W)				
1	1.034 (.150)	1.028 (.142)	1.000 (.000)	1.000 (.000)
2	1.378 (.412)*	1.277 (.349)*	1.414 (.317)	1.395 (.394)
3	1.276 (.307)	1.243 (.285)	1.341 (.338)	1.322 (.294)
4	1.495 (.528)**	1.346 (.500)**	1.466 (.499)	1.547 (.514)
5	1.745 (.611)	1.650 (.575)	1.552 (.619)	1.687 (.542)
6	2.255 (.478)	2.180 (.542)	2.173 (.576)	2.180 (.519)
7	2.219 (.543)	2.143 (.526)	2.224 (.610)	2.409 (.493)
8	2.008 (.523)***	1.781 (.532)***	1.977 (.584)	2.000 (.437)
9	1.880 (.557)***	1.600 (.525)***	1.881 (.710)	1.750 (.486)
10	2.136 (.552)	2.025 (.518)	2.111 (.518)	2.031 (.490)
11	2.312 (.567)	2.220 (.549)	2.207 (.563)	2.109 (.550)
12	1.733 (.511)	1.733 (.522)	1.704 (.616)	1.705 (.541)
Consistency (B)				
1	.959 (.167)	.975 (.120)	.862 (.351)	.969 (.177)
2	.688 (.312)	.764 (.274)	.539 (.321)	.574 (.322)
3	.770 (.244)	.789 (.240)	.617 (.339)	.479 (.361)
4	.550 (.433)**	.689 (.426)**	.379 (.456)	.172 (.350)
5	.348 (.418)	.399 (.449)	.414 (.468)	.292 (.430)
6	.150 (.261)	.197 (.290)	.167 (.276)	.121 (.192)
7	.097 (.208)	.109 (.213)	.167 (.276)	.121 (.192)
8	.220 (.323)***	.373 (.378)***	.247 (.358)	.125 (.220)
9	.275 (.370)***	.464 (.413)***	.241 (.366)	.240 (.371)
10	.221 (.309)*	.284 (.316)*	.207 (.285)	.131 (.231)
11	.114 (.255)	.151 (.305)	.129 (.318)	.125 (.298)
12	.355 (.357)	.368 (.383)	.313 (.380)	.266 (.387)

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

Table 18

Distribution of the Left-Handers and Right-Handers on the Laterality Factors as a Function of Sex

Factor	Sex	*n*	Left-hander (Score<3)	Ambidextrous (Score=3)	Right-hander (Score>3)
1	M	252	10.7%	0.0%	89.3%
	F	249	12.4%	0.0%	87.6%
2	M	245	9.8%	0.0%	90.2%
	F	249	10.8%	0.0%	89.2%
3	M	250	8.8%	0.4%	90.8%
	F	247	8.5%	0.0%	91.5%
4*	M	252	9.9%	5.6%	84.5%
	F	250	6.0%	2.4%	91.6%
5	M	252	20.6%	9.5%	69.8%
	F	250	22.0%	5.2%	72.8%
6	M	251	9.2%	6.4%	84.5%
	F	247	8.5%	6.1%	85.4%
7	M	250	9.6%	10.8%	79.6%
	F	249	7.2%	8.8%	83.9%
8**	M	250	13.6%	3.6%	82.8%
	F	249	9.6%	0.0%	90.4%
9*	M	249	13.3%	10.0%	76.7%
	F	248	9.7%	4.4%	85.9%
10***	M	245	14.7%	9.0%	76.3%
	F	249	10.0%	2.0%	88.0%
11**	M	251	17.5%	23.5%	59.0%
	F	250	12.4%	15.6%	72.0%
12	M	245	19.2%	3.3%	77.6%
	F	247	23.1%	2.8%	74.1%

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

certain activities, namely those related to strength.

The present study showed that the underlying constructs of handedness remain the same across sexes just as Bryden (1977) and Dean (1982) found. However, whereas Dean found females to be significantly more lateralized for all handedness factors including the general handedness factor, visually guided motor activities, and strength factor, the current study found sex differences only for Factors 4, 8, and 9 out of the 9 handedness factors. The common feature in these 3 factors was high strength. This suggests that activities for which males had less strong, less consistent hand preference than females were activities requiring high strength and that for these activities, males chose to use their dominant hand less often than did females. This also suggests that scores on these strength factors may make the largest contribution to the overall sex differences in hand preference.

These sex differences may be related to sex differences in overall hand strength. After pubescence, males develop significantly greater body strength, especially upper body strength, than females. For example, Peters and Servos (1989), using a dynamometer measure, estimated the mean strength of the dominant hand at 48.5 kg for college men compared to 27.1 kg for college women. The men's <u>nondominant</u> hand was far stronger than the women's <u>dominant</u> hand (46.4 kg versus 27.1 kg). Finally, the women had smaller between-hand strength differences than the men. When the differences in hand strength were expressed as a proportion of the strength of the stronger hand, the difference was 7.6% for men and 4.1% for women. These data suggest that post-adolescent males, compared to females, would have less need for consistently using their dominant (stronger) hand for activities requiring strength because their nondominant hand is also strong, whereas females would be more likely to consistently use their dominant hand for strength activities because even the smaller margin of greater strength favoring the dominant hand may be enough to tilt the balance in favor of dominant-hand use, since overall strength is less.

Peters and Servos' results also support Harris' (1990b) suggestion that sex differences in hand preference are stronger in less socially controlled acts than in more trained acts. Because the results of the current study also failed to reveal any sex differences in other factors (Factors 6 and 7) that include less socially controlled and less trained activities, they suggest that the strength dimension may be the more important contribution to sex differences in hand preference, at least among right-handers.

<u>Familial Sinistrality Based on Students' Reports</u>

Prevalence of familial sinistrality according to generation. The familial sinistrality data were classified into three groups based on subjects' reports about their own writing hand and that of their relatives: a first generation ("grandparents") group including the subjects' maternal and paternal grandparents ($\underline{n}$=1099), a second generation ("parents") group including the subjects' biological parents ($\underline{n}$=960), and a third generation ("children") group consisting of the subjects themselves ($\underline{n}$=500) and their biological siblings ($\underline{n}$=963). Table 19 shows the prevalence of left-handedness for males and females separately in each group. Only 4.8% of the grandparent group were classified as left-handed compared to 8.2% of the parents and 10.7% of the children. The grandparent and parent percentages were significantly different ($\chi^2(1)=9.91$, $\underline{p}<.001$), as were the percentages for children and parents ($\chi^2(1)=4.13$, $\underline{p}<.05$) and grandparents ($\chi^2(1)=29.12$, $\underline{p}<.001$). The results also found more left-handed males than females in the parents and grandparents groups, but the differences did not reach statistical significance.

Prevalence of familial sinistrality for subjects. The main subjects of the study (i.e., the college students) were classified in two ways -- first, if one or more immediate family members (parent or sibling) was reported as left-handed, the subjects were classified as

Table 19

Prevalence of Left-Handedness

Groups	Sex	# of cases	Left-handers n	%
Grandparents	M	487	29	6.0
	F	612	24	3.9
	M+F	1099	53	4.8
Parents	M	474	40	8.4
	F	486	39	8.0
	M+F	960	79	8.2
Children	M	716	70	9.8
(Students & Siblings)	F	747	87	11.6
	M+F	1463	157	10.7

Table 20

Prevalence of Familial Sinistrality (FS) for the Right-Handers and Left-Handers

	FS+	FS-	Total
Right-hander	135(32.6%)	279(67.4%)	414
Left-hander	20(34.5%)	38(65.5%)	58
Total	155(32.8%)	317(67.2%)	472

FS+. Using this decision rule, FS+ was reported by 32.8% of the respondents (see Table 20). Males and females did not differ on this measure, so they were combined for further analyses. The right-handers and the left-handers also reported similar prevalence of FS+ (32.6% versus 34.5%).

Subjects were reclassified as GPFS+ (positive grandparent-parent familial sinistrality) if one or more grandparent or parent was reported as left-handed. This analysis was based on the data of subjects who provided information about the writing hand of six persons (maternal grandparents, paternal grandparents and parents). Of 502 subjects, 50% provided this information. Among them, 46.8% of subjects reported GPFS+ (see Table 21). Sex differences were not found. Almost equal percentages of GPFS+ were reported from the right-handers (47%) and the left-handers (45.7%).

The parents of the subjects were grouped as follows: (1) two right-handed parents (RR), (2) right-handed mother and left-handed father (RL), (3) left-handed mother and right-handed father (LR), and (4) two left-handed parents (LL). Table 22 presents data on subjects' handedness according to parental handedness. It shows an increase in the percentage of left-handed offspring ranging from 12.6% in RR families and 5.4% in RL families to 18.8% in LR families. Neither increase was statistically significant, although the latter increase was marginally so ($\chi^2(1)=2.98$, $\underline{p}<.10$).

The presence of sinistrality in the subjects' siblings was also examined: 21.6% of the subjects reported that they had one or more left-handed sibling(s). Again, no sex difference and no handedness group difference was found.

Four familial handedness levels were examined: (1) all right-handed (no left-handed parents or siblings), (2) left-handed siblings only (both parents were right-handed), (3) left-handed parents only (all siblings were right-handed), and (4) left-handed siblings and left-

Table 21

Prevalence Grandparent-Parent Familial Sinistrality (GPFS) for the Right-Handers and Left-Handers

	GPFS+	GPFS-	Total
Right-hander	101(47.0%)	114(53.0%)	215
Left-hander	16(45.7%)	19(54.3%)	35
Total	117(46.8%)	133(53.2%)	250

Table 22

Prevalence of Left-Handed Sons and Daughters from 4 Types of Parents' Pairings

	Number of Left-Handers (%)		
Mother × Father (*n*)	Total	Son	Daughter
R × R (390)	49 (12.6%)	21 (10.3%)	28 (15.0%)
R × L (37)	2 (5.4%)	1 (7.1%)	1 (4.3%)
L × R (32)	6 (18.8%)	4 (22.2%)	2 (14.3%)
L × L (2)	0 (0.0%)	0 (0.0%)	0 (0.0%)

handed parents (at least one parent <u>and</u> one sibling were left-handed). No significant differences in the prevalence of left-handedness were found between levels.

The effects of FS+ on hand preference scores of the Lateral Preference Questionnaire also were examined. The direction and consistency within and between items were considered for the total group and for each handedness group as a function of FS. No significant differences were found between FS+ group and FS- group. Subjects' hand preference scores for each handedness factor were also recoded so that individuals with a mean preference score not greater than 3 received a score of 1 and individuals with a preference score greater than 3 received a score of 2. Subjects of FS+ group received a score of 1 and subjects of FS- group received a score of 2. Correlation coefficients between each handedness factor and FS were then computed. No significant correlations were found.

Discussion. The overall results showed significant differences in the prevalence of left-handedness between generations. This difference has been noted in virtually every family study of handedness, regardless of the handedness measure used (Annett, 1973, 1978; Ashton, 1982; Brackenridge, 1981; Carter-Saltzman, 1980; Falek, 1959; Levy, 1976; McGee & Cozad, 1980). The current results, in particular, showed double generation effects like those of Annett (1978), who reported data for parents and children of the same respondents (University students), three generations in all, and found an inverse relation between subject age and prevalence of left-handedness. McGee and Cozad (1980) reviewed previous studies from Ramaley (1912) to Annett (1978) and found a mean increase in left hand preference of about 4% in one generation, offspring over parents. Levy (1976) also reported a "monotonic increase in manifest sinistrality" (p. 430) from 1932 to 1972 and suggested that the reduction in social pressure toward dexterity and associated increase in acceptance of sinistrality led to an increase in the manifestation of left-handedness.

In the present study, right and left-handers reported FS+ with approximately equal frequency (32.6% versus 34.6%). Although some studies (e.g, Briggs & Nebes, 1975; Searleman et al., 1979) have reported a significant relationship between subjects' handedness and FS, others (e.g., Spiegler & Yeni-Komshian, 1983) have not. Following Bishop's (1980) suggestion, the current study measured GPFS so as to avoid the possibility of a systematic bias from differences in family size. Again, approximately equal frequencies of GPFS+ were reported by right- and left-handers (47% versus 45.7%). Because these data constitute the first use of this measure from a large sample, there are no data with which they can be compared. The results showed that GPFS+ was more frequent than FS+. However, if we consider that the GPFS frequencies were based on reports from only about half of the total sample, the possibility of bias in the GPFS frequencies cannot be discounted.

Many studies have reported that the percentage of left-handed offspring is greater if one parent, especially the mother, is left-handed than if neither parent is left-handed (e.g., Annett, 1973, 1978; Ashton, 1982; Longstreth, 1980; McGee & Cozad, 1980; Rife, 1940). McGee and Cozad's (1980) study showed that although not all of the differences in these studies were statistically significant, when the results were compiled, a robust maternal effect was clearly evident. Likewise, in the present study, the maternal effect was not statistically significant, but it was in the predicted direction, with left-handedness more prevalent in children with a right-handed father and left-handed mother than in children with a left-handed father and right-handed mother. Small sample sizes in the RL, LR, or LL mating types may have contributed to the lack of statistical significance in the present study.

Leiber and Axelrod (1981) found, in a sample of 1631 subjects, that FS+ right- and left-handers were less strongly and less consistently right- or left-handed than FS- subjects, although the magnitude of effects was very small. However, the present study did not find any variation in direction or consistency (either between- or within-item) as a function of FS. Nor were there any specific handedness factors significantly correlated with FS. Again, it may be important that the sample size of the present study was much smaller than in previous studies that have found significant FS effects.

Comparison Between Parents' Self-Reports of Handedness and Offsprings' Reports about Parents' Handedness

The preceding analysis used the primary subjects' own reports as the estimate of family handedness. Although this is the usual measure in family handedness studies, it does raise the question of accuracy of report. The present study therefore tried to assess the validity of these reports by comparing the students' reports with those made by their own parents who replied to the mail questionnaire.

Ninety-three subjects reported that their parents had divorced or that one or both parents had died before the subject was 8 years old. Forty subjects reported that their parents had divorced after the subject was 8 years old, and 369 subjects reported that their parents were still married. Questionnaires were mailed to each parent whose address was known to the subject except for the (living) parents in the first group. Of the eligible group of 409 parents, 64% returned the questionnaires, which included 243 complete sets (both mother and father), 14 fathers, and 25 mothers.

Parents' handedness based on writing hand. Table 23 shows the frequency of parents' self-reports of writing hand tabulated against students' reports of parents' writing hand. Students' reports were based on their answer to a single question about the parents' writing hand. Parents' self-report of writing hand was based on the 5-point scale. Except for one father who reported that he "usually" writes with

Table 23

Frequency (Percentage) of Parents Self-Reports of Writing Hand Tabulated Against Offsprings' Reports of Parents' Writing Hand

Offsprings' Report of Parents' Writing Hand		Parents' Self-Report of Writing Hand: Left	Right	Total
MOTHER				
	Left	19(7.1)	4(1.5)	23(8.6)
	Either	0(0.0)	1(0.4)	1(0.4)
	Right	0(0.0)	244(91.0)	244(91.0)
	Total	19(7.1)	249(92.9)	268
FATHER				
	Left	20(7.9)	1(0.4)	21(8.3)
	Either	0(0.0)	1(0.4)	1(0.4)
	Right	2(0.8)	229(90.5)	231(91.3)
	Total	22(8.7)	231(91.3)	253
TOTAL				
	Left	39(7.5)	5(1.0)	44(8.4)
	Either	0(0.0)	2(0.4)	2(0.4)
	Right	2(0.4)	473(90.8)	475(91.2)
	Total	41(7.9)	480(92.1)	521

his right hand, all parents reported that they "always" use their right or left hand. Therefore, every parent's writing hand could be classified as right or left without using the "either" category. Because writing is an overt behavior easily observed in everyday life, one would expect the students' reports to be highly accurate. The results confirmed this expectation: 98.3% of the students reported their parents' writing hand correctly, and only 6 students (1.1%) reported that they did not know which hand their parents used for writing. The students' reports about each parent's writing hand were equally accurate (98.1% for the mothers' writing hand versus 98.4% for the fathers'). The results also showed that students were more accurate for parents who were right-hand writers than left-hand writers, although this difference was not statistically significant ($\chi^2(1)=2.6$, ns). If only the students' reports of parental writing hand were used for measuring parental writing hand, only 1.5% of the parents who were right-hand writers and 4.9% of the left-hand writers would be misclassified.

Parents' general handedness based on handedness inventory. The parents' handedness inventory consisted of 10 skilled, unimanual, distal behaviors. Each parent was classified as left-handed, ambidextrous, or right-handed based on the mean score of the handedness inventory as follows: Each individual was classified as right-handed if the mean handedness score was greater than 3, as ambidextrous if the mean score was equal to 3, as left-handed if the mean score was less than 3. Parents' general handedness based on this classification was compared with students' reports of their parents' general handedness (Table 24). Students' reports were based on their response to a single question about parental general handedness. Seven students reported that they did not know their parents' handedness. There were 57 cases (11.1%) in which parental handedness was misclassified. This result also showed that if the data about parental handedness were based on only the offsprings' reports, 37% of the left-handers and 9.1% of the right-

Table 24

Frequency Distribution of Parents' Handedness Score Tabulated Against Offsprings' Report of Parents' General Handedness

Offerings' Report of Parents' General Handedness	Parents' Handedness Score			
	Left	Ambidextrous	Right	Total
MOTHER				
Left	11 (4.2)	0 (0.0)	5 (1.9)	16 (6.1)
Ambidextrous	4 (1.5)	0 (0.0)	12 (4.5)	16 (6.1)
Right	1 (0.4)	0 (0.0)	231 (87.5)	232 (87.9)
Total	16 (6.1)	0 (0.0)	248 (93.9)	264
FATHER				
Left	11 (4.4)	1 (0.4)	3 (1.2)	15 (6.0)
Ambidextrous	6 (2.4)	1 (0.4)	23 (9.2)	30 (12.0)
Right	2 (0.8)	0 (0.0)	203 (81.2)	205 (82.0)
Total	19 (7.6)	2 (0.8)	229 (91.6)	250
TOTAL				
Left	22 (4.3)	1 (0.2)	8 (1.6)	31 (6.0)
Ambidextrous	10 (1.9)	1 (0.2)	35 (6.8)	46 (8.9)
Right	3 (0.6)	0 (0.0)	434 (84.4)	437 (85.0)
Total	35 (6.8)	2 (0.4)	474 (92.2)	514

handers among parents would be misclassified. This result is consistent with Porac and Coren's (1979) report that high school children underestimated the proportion of parental sinistrality. The overall correctness of the students' report about parental handedness was 88.9%. This rate was significantly lower than that of students' report about parental writing hand ($\chi^2(1)=37.99$, $p<.001$). However, whether writing hand is a good measure for studying the genetic component of handedness or for assessing familial handedness is another matter and remains controversial. The results also showed that a slightly but significantly larger percentage of students correctly reported their mother's handedness than their father's handedness (91.7% versus 86.0%; $\chi^2(1)=4.18$, $p<.05$). This difference perhaps reflects a greater number of social interactions between the students and their mothers than their fathers, although, if so, the size of the difference implies that any such social-interactional differences must be very small.

Another example of the students' classification errors was their designation of a relatively large percentage (8.9%) of their parents as ambidextrous. Students classified 46 parents as ambidextrous. According to the parents' self-reports, however, there was only 1 ambidextrous parent among those classified as ambidextrous by their children. Of the rest of this group of parents, 35 were classified as right-handed, and 10 as left-handed, based on parents' self-reports. Although the criterion used to classify parents' handedness was arbitrary, as previously noted, students evidently also have a different arbitrary criterion (especially in relation to the "ambidextrous" category) for categorizing parents' handedness.

Parents' handedness based on students' handedness. The data were also examined as a function of students' handedness (Table 25). Of the left-handed students, 97.2% reported parental handedness correctly (i.e., in agreement with parents' own report) against 87.5% for the right-handers. This difference was statistically significant

Table 25

Frequency (Percentage) Distribution of Parents' Handedness Scores Tabulated Against Offsprings' Reports of Parents' General Handedness According to Offsprings' Handedness

Offsprings' Report of Parents' General Handedness	(Right-Handed Offsprings' Report) Parents' Handedness Score				(Left-Handed Offsprings' Report) Parents' Handedness Score			
	Left	Ambidextrous	Right	Total	Left	Ambidextrous	Right	Total
MOTHER								
Left	10 (4.4)	0 (0.0)	4 (1.8)	14 (6.2)	1 (2.8)	0 (0.0)	1 (2.8)	2 (5.6)
Ambidextrous	4 (1.8)	0 (0.0)	12 (5.3)	16 (7.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Right	1 (0.4)	0 (0.0)	196 (86.3)	197 (86.8)	0 (0.0)	0 (0.0)	34 (94.4)	34 (94.4)
Total	15 (6.6)	0 (0.0)	212 (93.4)	227	1 (2.8)	0 (0.0)	35 (97.2)	36
FATHER								
Left	9 (4.2)	0 (0.0)	3 (1.4)	12 (5.6)	2 (5.7)	1 (2.9)	0 (0.0)	3 (8.6)
Ambidextrous	6 (2.8)	1 (0.5)	23 (10.7)	30 (14.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Right	2 (0.9)	0 (0.0)	170 (79.4)	172 (80.4)	0 (0.0)	0 (0.0)	32 (91.4)	32 (91.4)
Total	17 (7.9)	1 (0.5)	196 (91.6)	214	2 (5.7)	1 (2.9)	32 (91.4)	35
TOTAL								
Left	19 (4.3)	0 (0.0)	7 (1.6)	26 (5.9)	3 (4.2)	1 (1.4)	1 (1.4)	5 (7.0)
Ambidextrous	10 (2.3)	1 (0.2)	35 (7.9)	46 (10.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Right	3 (0.7)	0 (0.0)	366 (83.0)	369 (83.7)	0 (0.0)	0 (0.0)	66 (93.0)	66 (93.0)
Total	32 (7.3)	1 (0.2)	408 (92.5)	441	3 (4.2)	1 (1.4)	67 (94.4)	71

($\chi^2(1)=5.76$, $p<.05$). It is noteworthy that none of the left-handed parents were misclassified by left-handed students, whereas 40.6% of the left-handed parents were misclassified by right-handed students. Right-handed students misclassified 31.3% of their left-handed parents as ambidextrous and 9.3% of them as right-handed. Finally, right-handed students reported their mothers' handedness more correctly than their fathers' handedness (90.7% versus 84.1%, $\chi^2(1)=4.44$, $p<.05$). Left-handed students were just as accurate for mothers as for fathers (97.2% versus 97.1%). These results strongly support previous reports (Etaugh & Brausam, 1978; McGuire & McGuire, 1980; Thompson & Harris, 1978) that left-handers are more sensitive than right-handers to hand usage. Thompson and Harris (1978) suggested that handedness has greater salience in left-handers' self-concepts because of the numerical rarity of left-handedness in the population.

The present study shows that there are systematic differences between students' report of parental handedness and parental handedness as reported by the parents themselves. It thus suggests that although children's reports of their parents' writing hand are highly accurate, researchers should be very cautious in using children's reports of parental general handedness, even adult children's reports, especially if the children are right-handed.

<u>Hand Preference Change</u>

Results. In the total sample (N=502), 273 subjects (54.4%) reported that neither they themselves nor anyone else had ever tried (had applied "overt pressure") to change their "natural handedness" (No-Change Group). By contrast, 135 (26.9%) reported that they had such an experience imposed by other person(s), regardless of whether the subjects themselves had imposed pressure (Hand-Change Group); of this group, 82 subjects (16.3%) reported that the attempts had been successful (Successful Hand-Change Group). Finally, in the total sample, 76 subjects (15.1%) reported that they tried to change their handedness by themselves without any other person's direct influence (Self Hand-Change Group). When the socioeconomic status measured by the Duncan Socioeconomic Index (Stevens & Featherman, 1980) and maternal and paternal education level were compared, no differences were found among these four groups.

The Hand-Change Group included 80 males (59.3%) and 55 females (40.7%), while the No-Change Group included 124 males (45.4%) and 149 females (54.6%). The sex difference was statistically significant in the Hand-Change Group ($\chi^2(1)=4.63$, $p<.05$). The prevalence of sinistrality (FS+) among the first-degree relatives (parent or sibling) was identical between these two groups (33%).

The Hand-Change Group consisted of 37 subjects who reported a change attempt from left-handed or ambidextrous to right-handed (Right-Shift Group), 17 subjects from left-handed to ambidextrous (Left-Ambidextrous Group), 69 subjects from right-handed to ambidextrous (Right-Ambidextrous Group), and 12 subjects from right-handed or ambidextrous to left-handed (Left-Shift Group). Table 26 compares the four groups on the characteristics of the hand change attempts. None of the groups showed sex differences in relation to any of the characteristics.

In the Right-Shift Group, parents (40%) or teachers (23.3%) were named as the most influential persons for instituting change of hand use, with hand use for writing (40.6%) and sports (34.4%) being the most frequently-mentioned targets. These attempts started very early in life and continued after late childhood years. In the Left-Ambidextrous Group, the subjects themselves (50%) or their parents (24%) were named as the most influential person, with sports (56.2%) and writing (31.3%) being the most frequently-named targets. This attempt started later than that of the Right-Shift Group ($\chi^2(3)=9.51$, $p<.05$). The Right-Ambidextrous Group included more males than females (64% versus 36%, $\chi^2(1)=5.23$, $p<.05$) and showed very different characteristics from the

Table 26

Comparisons of Timing, Agents, Target Behaviors, and Success Rate of Handedness Change Attempts of Each Attempt Group

	Left-Shift n=12 (M:5 F:7)	Right-Ambi n=69 (M:44 F:25)	Left-Ambi n=17 (M:7 F:10)	Right-Shift n=37 (M:24 F:13)	Self-Change n=76 (M:39 F:37)
First attempt					
Before primary school	25.0(3)	4.4(3)**	17.6(3)	51.4(19)**	1.3(1)**
Grade 1-3	25.0(3)	8.8(6)**	29.4(5)	32.4(12)**	6.6(5)**
Grade 4-6	8.3(1)	55.9(38)**	17.6(3)	2.7(1)**	28.9(22)**
After grade 6	41.7(5)	30.9(21)**	35.3(6)	13.5(5)**	63.2(48)**
Last attempt					
Before primary school	8.3(1)	2.9(2)**	11.8(2)	35.1(13)	1.3(1)**
Grade 1-3	16.7(2)	0.0(0)**	23.5(4)	24.3(9)	1.3(1)**
Grade 4-6	25.0(3)	19.1(13)**	11.8(2)	13.5(5)	10.5(8)**
After grade 6	50.0(6)	77.9(53)**	52.9(9)	27.0(10)	86.8(66)**
Effective person					
Self	27.3(3)	46.8(29)**	50.0(8)	10.0(3)*	100.0(76)**
Parents	27.3(3)	16.1(10)**	25.0(4)	40.0(12)*	0.0(0)**
Mother	9.1(1)	0.0(0)	6.3(1)	16.7(5)	0.0(0)
Father	18.2(2)	16.1(10)	18.8(3)	23.3(7)	0.0(0)
Teacher	18.2(2)	6.5(4)**	6.3(1)	23.3(7)*	0.0(0)**
Coach	27.3(3)	19.4(12)**	0.0(0)	6.7(2)*	0.0(0)**
Others	0.0(0)	11.2(7)**	18.8(3)	20.0(5)*	0.0(0)**
Target Behavior					
Writing	36.4(4)	13.6(9)**	31.3(5)*	40.6(13)**	47.6(30)**
Eating	9.1(1)	4.5(3)**	0.0(0)*	12.5(4)**	9.5(6)**
Sports	45.5(5)	72.7(48)**	56.2(9)*	34.4(11)**	38.1(24)**
Others	9.1(1)	9.1(6)**	12.5(2)*	12.5(4)**	4.8(3)**
Success rate	50.0(6)	65.2(45)	41.2(7)	59.5(22)	41.3(31)
If successful, when?					
Before primary school	0.0(0)	2.2(1)**	0.0(0)	31.8(7)	0.0(0)**
Grade 1-3	40.0(2)	2.2(1)**	14.3(1)	27.3(6)	6.7(2)**
Grade 4-6	0.0(0)	17.6(8)**	28.6(2)	22.7(5)	6.7(2)**
After grade 6	60.0(3)	78.0(35)**	57.2(4)	18.2(4)	87.7(26)**

* Significant deviation from equal proportions within groups (p<.01).

** Significant deviation from equal proportions within groups (p<.001).

Right-Shift Group. In contrast to the Right-Shift Group, the subjects in the Right-Ambidextrous Group named themselves (46.8%) as the most influential person, although sport coaches (19.4%) and fathers (16.1%) were also reported to be influential. The change attempts occurred from late childhood (86.8%) and most changes were accomplished after the primary school years. The target behavior was usually sports (72.7%). In the Left-Shift Group, the change attempts occurred late and continued late, although, in comparison to the Right-Ambidextrous Group, they started earlier ($\chi^2(3)=54.2$, $p<.001$) and discontinued earlier ($\chi^2(3)=13.38$, $p<.01$). The primary targets were sports (45.5%) and writing (36.4%).

The Self Hand-Change Group consisted of 39 males and 37 females of whom 29.9% were FS+. About 90% (68 subjects) of this group reported having tried to change from right-handed to ambidextrous, 3 subjects from right-handed or ambidextrous to left-handed, 1 subject from left-handed or ambidextrous to right-handed, and 4 subjects from left-handed to ambidextrous. Of the 76 subjects who reported that they had tried to change their handedness, 92.1% reported that they had begun in late childhood or after childhood. Although most of the Self Hand-Change Group subjects tried to change in the same direction as the Right-Ambidextrous Group of the Hand-Change Group, their attempts to change started later ($\chi^2(3)=72.11$, $p<.001$). Finally, the Self Hand-Change subjects' target behaviors were nearly equally divided into writing (47.6%) and sports (38.1%), whereas the Right-Ambidextrous Group focused more on sports (72.7%).

The overall self-described success rate was 52.6% in the Hand-Change Group and 41.3% in the Self Hand-Change Group. No between-group differences of success rate were found among the four different groups comprising the Hand-Change Group. However, the Right-Ambidextrous Group in the Hand-Change Group showed a higher success rate than the Right-Ambidextrous Group in the Self Hand-Change Group ($\chi^2(1)=8.84$, $p<.01$).

Left-handers are likely to have experienced varying degrees of overt and covert pressure to shift toward right-hand use. Therefore, in the Hand-Change Group, those individuals who reported being pressed to change to right-hand use (the Right-Shift Group) have been the main interest. Of the total number of hand change attempts reported, 7.4% were in the rightward direction, and the success rate of the Right-Shift Group was 59.5%. There was no sex difference in success rate (male 62.5%, female 53.8%). Table 27 shows the characteristics of the successful Right-Shift Group. Successful right-shift was most likely to occur at the prompting of parents during the early childhood years. Of those who shifted, over 80% reported that they made the change before graduation from primary school. The most frequent target behaviors were writing (39.3%), sports (25%), and eating (21.4%). No sex differences were found.

Self-reports of hand-change compared to handedness score on questionnaire. The success rates in all of the preceding analyses were based on subjects' self-reports. In order to assess the accuracy of these self-reports, subjects' self-reported shift categories were compared with their self-classifications of general handedness and the direction and consistency of their hand preference scores on the Lateral Preference Questionnaire. These scores are presented for the Successful Hand-Change Group and the No-Change Group in Table 28. All subjects in the successful Left-Shift Group still called themselves right-handers, whereas only one self-classified left-hander was in the successful Right-Shift Group. The successful Left-Ambidextrous Group included 5 self-classified left-handers and 2 right-handers, whereas all subjects in the successful Right-Ambidextrous Group still classified themselves as right-handers, with 70% even declaring themselves to be "strong" right-handers. The discrepancy between self-classified handedness and self-reported success of handedness change indicates that subjects' hand preference change was incomplete, even though all subjects in the Self

Table 27

Timing, Agents, Target Behaviors of Handedness Change attempts in The Successful Right-Shift Group

	Total (n=22)	Male (n=15)	Female (n=7)
First attempt			
Before primary school	59.1(13)**	60.0(9)**	57.1(4)
Grade 1-3	31.8(7)**	40.0(6)**	14.3(1)
Grade 4-6	4.5(1)**	0.0(0)**	14.3(1)
After primary school	4.5(1)**	0.0(0)**	14.3(1)
Last attempt			
Before primary school	36.4(8)	0.0(6)	28.6(2)
Grade 1-3	22.7(5)	20.0(3)	28.6(2)
Grade 4-6	18.2(4)	20.0(3)	14.3(1)
After primary school	22.7(5)	20.0(3)	28.6(2)
When changed?			
Before primary school	31.8(7)	35.7(5)	28.6(2)
Grade 1-3	27.3(6)	35.7(5)	14.3(1)
Grade 4-6	22.7(5)	14.3(2)	42.9(3)
After primary school	18.2(4)	14.3(2)	14.3(1)
Effective Person			
Self	11.1(2)*	9.1(1)*	14.3(1)
Parents	61.1(11)*	63.7(7)*	57.2(4)
Mother	27.8(5)	27.3(3)	28.6(2)
Father	33.3(6)	36.4(4)	28.6(2)
Teacher	11.1(2)*	9.1(1)*	14.3(1)
Coach	5.6(1)*	0.0(0)*	14.3(1)
Others	11.1(2)*	18.2(2)*	0.0(0)
Target behavior			
Writing	39.3(11)	45.0(9)	25.0(2)
Eating	21.4(6)	25.0(5)	12.5(1)
Sports	25.0(7)	15.0(3)	50.0(4)
Others	14.3(4)	15.0(3)	12.5(1)

* Significant deviation from equal proportions within groups ($p<.01$).

** Significant deviation from equal proportions within groups ($p<.001$).

Table 28

Comparison of The Successful Hand-Change Group and the No-Change Group

	Hand-Change Group					
	Left-Shift	Right-Ambi	Left-Ambi	Right-Shift	Total	No-Change Group
Self-classified Handedness						
Right	6(100.0%)	44(100.0%)	2(28.6%)	21(95.5%)	73(92.4%)	243(89.0%)
Left	0(0.0%)	0(0.0%)	5(71.4%)	1(4.5%)	6(7.6%)	30(11.0%)
Total	6	44	7	22	79	273
Direction and Consistency(W)						
Right	4.173(.368)	4.055(.431)	4.280(.113)	4.090(.495)	4.101(.401)***	4.264(.324)***
Left	---	---	2.095(.427)	---	2.095(.427)	2.488(.687)
Total	4.173(.368)	4.055(.431)	2.823(1.177)	4.090(.495)	3.973(.624)*	4.074(.665)*
Consistency(W)						
Right	1.753(.469)	1.837(.324)	1.660(.198)	1.822(.443)	1.827(.365)***	1.672(.296)***
Left	---	---	1.925(.293)	---	1.925(.293)	1.801(.311)
Total	1.753(.469)	1.837(.324)	1.837(.279)	1.822(.443)	1.827(.360)*	1.689(.302)*
Consistency(B)						
Right	.417(.335)	.394(.204)	.450(.099)	.424(.269)	.404(.227)***	.497(.198)***
Left	---	---	.352(.206)	.600(.000)	.393(.210)	.355(.164)
Total	.417(.335)	.394(.204)	.380(.180)	.432(.265)	.399(.228)**	.479(.201)**

Hand-Change Group declared that their changes had been successful.

Examinations of the direction and consistency (W), consistency (W), and consistency (B) of hand preference showed that right-handers in the Self Hand-Change Group had significantly less lateralized and less consistent right-hand preference than right-handers in the No-Change Group. The left-handers were not considered for these examinations because of the very small number of left-handers in the Self Hand-Change Group. Mean hand preference scores for each factor of four groups in the successful Hand-Change Group were compared with those of right- and left-handers in the No-Change Group (Table 29). No significant difference was found between the successful Left-Ambidextrous Group and the left-handers in the No-Change Group when the direction and consistency (W) of hand preference were considered jointly based on the total hand preference score. However, from the examinations of each factor score, a significant difference was found for Factor 1 ($z=2.09$, $p<.05$) between these two groups, reflecting the successful Left-Ambidextrous Group's weaker left-hand score in writing and drawing. The successful Right-Shift Group was compared with right-handers in the No-Change Group on direction and consistency (W). The total hand preference score showed that the successful Right-Shift Group tended to be more weakly right-handed than the right-handers, although the difference was not significant ($z=-1.83$, $p=.07$). Factor scores showed that subjects in the successful Right-Shift Group were still less strongly lateralized in skilled unimanual activities (Factors 2 and 3, $p<.01$) than right-handers in the No-Change Group, although no differences were found for Factor 1 (writing and drawing) between these two groups. When the successful Right-Ambidextrous Group was compared with right-handers in the No-Change Group, the Right-Ambidextrous Group showed significantly weaker right-handed responses than the right-handers. Significant differences in hand preference scores were found for Factors 1 ($z=3.40$, $p<.001$), 2 ($z=4.59$, $p<.001$), 3 ($z=2.17$, $p<.05$), 6

Table 29

Mean Preference Score (Standard Deviation) on the Handedness Factors of the Successful Hand-Change Group and the No-Change Group

	Hand-Change Group				No-Change Group	
Factor	Left-Shift	Right-Ambi	Left-Ambi	Right-Shift	Right-Hander	Left-Hander
1	5.000 (.000)	4.478 (.323)	2.174 (2.138)	4.795 (.854)	4.955 (.369)	1.400 (1.221)
2	4.354 (.599)	4.412 (.510)	2.857 (1.801)	4.295 (.809)	4.711 (.402)	2.204 (1.142)
3	4.463 (.441)	4.662 (.405)	2.905 (1.588)	4.302 (.940)	4.781 (.278)	2.138 (1.328)
4	3.778 (1.409)	3.696 (1.159)	2.857 (1.864)	3.606 (1.185)	3.929 (1.013)	2.111 (1.276)
5	4.417 (.492)	4.322 (.732)	2.857 (1.701)	4.273 (1.152)	4.508 (.682)	2.917 (1.619)
6	3.595 (.456)	3.514 (.477)	3.204 (.958)	3.649 (.763)	3.830 (.554)	2.690 (.783)
7	3.983 (.801)	3.680 (.621)	3.129 (.966)	3.668 (.719)	3.827 (.580)	2.843 (.605)
8	4.500 (.422)	3.852 (.679)	2.714 (.966)	3.856 (.847)	4.114 (.579)	2.529 (.891)
9	3.833 (1.070)	3.682 (.835)	2.857 (1.136)	3.905 (.870)	4.148 (.779)	2.967 (1.323)

(z=3.66, p<.001), 8 (z=2.49, p<.05), and 9 (z=3.65, p<.001).

Discussion. Porac et al. (1990) reviewed 9 recent studies about hand change attempts. They found that the mean rate of hand change attempt was 8.9%, although the frequency of occurrence varied greatly across studies (0.7% - 24.1%). Compared to the previous studies, the frequency rate of the current study (26.9%)[11] is surprisingly high. It is also clear that change attempts toward the left side (the Left-Shift Group and the Right-Ambidextrous Group) were far more common than change attempts toward the right side (the Right-Shift Group and the Left-Ambidextrous Group), with frequency rates of 72% versus 28%. However, when the "real" right- and left-shift attempts whose goals were to be "exclusive" right- or left-handed were considered separately, it was found that right-shift attempts (18% of the total number of change attempts) were more common than left-shift attempts (7.1%) as would expected according to a right-sided world hypothesis.

Porac et al. (1990) found a higher success rate in their left-shift group (corresponding to the Left-Shift Group and the Right-Ambidextrous Group in the present study) than in their right-shift group (the Right-Shift Group and the Left-Ambidextrous Group in the present study). However, the present study did not find any significant differences in success rate among the four attempt groups (see Table 26), although the Right-Ambidextrous Group showed the highest success rate and had a slightly higher success rate than the Left-Ambidextrous Group ($\chi^2(1)$=3.58, p=.06). This result suggests that Porac et al.'s (1990) report of a higher success rate in the left-shift group reflects the high success rate of their right-ambidextrous group rather than the "real" left-shift group.

Previous studies have reported a significant overrepresentation of females in hand-change groups (e.g, Dawson, 1977; Levy, 1974; Porac &

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[11] This figure does not include the Self Hand-Change Group because most of the previous studies did not include this group.

Coren, 1981). In the current study, the only sex difference was in the reverse direction. Significantly more males than females were found in the Hand-Change Group. Specifically, there were more males in the Right-Ambidextrous Group among the 4 subgroups of the Hand-Change Group ($\chi^2(1)=5.23$, $p<.05$). Porac et al. (1986) also found a sex difference in the success rates of hand shifts, with female reporting more success. No such differences appeared in the current study.

One finding worth special mention is the existence of the Right- and Left-Ambidextrous group, which included a large proportion of the individuals in the Hand-Change Group and the Self Hand-Change Group (74.9% of the total number of hand-change attempts). Many more subjects were found in the Right-Ambidextrous Group (*n*=137) than in the Left-Ambidextrous Group (*n*=21), because the current sample consisted of a lot of right-handers and a small number of left-handers. In both Ambidextrous Groups, however, the goal was to be ambidextrous rather than to change handedness, either from right to left or left to right. Their hand-change attempts were primarily self-generated, out of personal interest or experimentation. Frequent responses from this group were, "I was just curious to see if I could actually write legibly with my left hand," "It was an experiment to see if I could write with both hands after I practiced it enough," "I wanted to be able to write with either hand because it seemed like it would be cool. It's also for fun," and "To be a more well rounded better basketball player, I wanted to be able to dribble and shoot with either hand, not just my right one." This group, it perhaps could be said, represents contemporary proponents of the "Ambidextrous Culture Movement" of the late 19th and early 20th centuries in the United States and Great Britain. This movement advocated the benefits of using both hands, for left- and right-handers alike, in such activities as medicine, sports, and military training (see Harris, 1985, for a review).

Despite their similarities, there were some differences between the Right-Ambidextrous Group in the Hand-Change Group and the Right-Ambidextrous Group in the Self Hand-Change Group. First, the Right-Ambidextrous Group in the Hand-Change Group described themselves as having had the most influence, they also reported having received overt pressure from other person(s) such as the father or athletic coaches (e.g., baseball, basketball, volleyball, gymnastics, softball, golf). Second, in most cases their change attempts focused only on sports (72.7%). Examples of frequent responses were, "Father got me to bat both ways in baseball," and "Basketball coach wanted me to learn to dribble with left hand." By contrast, the change attempts of the Right-Ambidextrous Group in the Self Hand-Change Group were more self-generated, that is, were more often made in the absence of overt pressure, and were more experimental and casual. They also occurred later and focused on writing (47.6%) and sports (38.1%). Examples of frequent responses from the Self Hand-Change Group were, "I wanted to learn to write and eat with my left hand in case something ever happened to my right hand or arm," and "I tried to become ambidextrous, so I could be able to be a better basketball player." The Right-Ambidextrous Group of the Self Hand-Change Group also showed lower success rates then that of the Hand-Change Group ($\chi^2(1)=8.84$, $p<.01$). The subjects in the Right-Ambidextrous Group of the Self Hand-Change Group thus seem to be the truer descendants of the "Ambidextral Culture Movement" in the sense that they themselves realized the benefits to be ambidextrous and tried to be ambidextrous for themselves without any external pressure. Similar comparisons could not be made for the Left-Ambidextrous Groups because the sample sizes were too small.

The incompleteness of hand preference change, especially in the right-shift group, has been reported by several researchers (Dean, Rattan, & Hua, 1987; Leiber & Axelrod, 1981; Porac et al., 1990; Teng et al., 1976). The present data support these previous reports. The significant differences found for Factors 2 and 3 between the successful

Right-Shift Group and the right-handers in the No-Change Group indicate that although the Right-Shift Group successfully changed their handedness for writing and drawing (Factor 1) -- behaviors that were the most frequently targeted for handedness change -- they continued with left-hand use or did not reach the same levels of right-handedness as did the right-handers of the No-Change Group for the other unimanual, skilled behaviors. This suggests that their hand shift attempts were only partially successful. It also suggests that hand writing is still subject to the strongest social or cultural pressure toward right-handedness and is the most important criterion by which subjects classify handedness. This suggestion is supported by the comparison between the successful Left-Ambidextrous Group and the left-handers of the No-Change Group, which found a between group difference only for Factor 1 (writing and drawing), even though the Left-Ambidextrous Group declared that they had successfully changed from being left-handed to being ambidextrous. Whereas no significant difference was found for 7 of 9 factors between the Right-Shift Group and the right-handers of the No-Change Group, significantly different hand preference scores for 6 of 9 factors were found between the Right-Ambidextrous Group of the Hand-Change Group and the right-handers of the No-Change Group. This suggests that relatively diverse behaviors were influenced by hand change attempt in the Right-Ambidextrous Group, although it was still incomplete.

One question related to this issue is whether left- or right-handers in the Hand-Change Group originally intended to change hand use for all kinds of behaviors or for only some behaviors such as writing, eating, or sports. The results point to the latter inasmuch as writing, eating, and sports comprised 90% of the targeted behaviors in the Hand-Change Group.

Leiber and Axelrod (1981) found that intentional reversal of handedness resulted in decreased strength and consistency of hand usage, regardless of the direction of change. They concluded that this is a sign of the incompleteness of hand preference change. Similar results were found in the current study but only for right-handers, although the nonsignificant results for left-handers could have resulted from the small sample sizes in each category.

Along with the question of the broadness or narrowness of the behaviors targeted for change, there is the question of distinguishing those persons who wanted to make a complete switch in hand-use from those who merely wanted to be ambidextrous. Many (63.7%) of those in the Hand-Change Group indicated that they sought ambidexterity rather than a complete switch to right- or left-handedness. As one subject said, "Father did not really force major change in handedness, he just taught me to equalize use of both hands in basketball." Therefore, previous studies (Porac et al. 1986, 1990) that have failed to differentiate these two groups might not be correct in their account of the degree of incompleteness of hand-change. For example, Porac et al. (1990) found a large discrepancy between the self-rated success rate (34.2%) and the success rate based on handedness questionnaire scores (3.6%) in their left-shift group, whereas their right-shift group showed consistent success rates between two measures (33.3% and 34.5%). They concluded that this difference reflected the different criteria of success used by the two shift groups. That is, right-handers attempting to use the left hand may have rated this shift attempt as successful when a transitory or unstable use of the left hand was achieved, whereas left-handers may have rated the shift as successful only if the change to right-hand use had become a permanent part of everyday behavior. The present data, however, suggest that Porac et al.'s (1990) left-shift group included many Right-Ambidextrous Group subjects. In other words, including these subjects would have resulted in a low success rate because their success would have been judged in terms of the left-hander category of the handedness questionnaire score, although their goal, which they evidently reached, was to be ambidextrous. Therefore, in any assessment of the "completeness" of hand-use change, individuals who want to be exclusively right- or left-handed must be analyzed separately from those who want to be ambidextrous.

In sum, the present data show that overt hand change attempts are common among American college students, with the vast majority of attempts for the purpose of achieving ambidextrous skill. Sports evidently figures importantly in this choice. These results thus demonstrate that handedness can be affected by external influences and personal motivation; they also indicate that there are limits to this plasticity.

Hand Preference and Hand Performance

Results. The correlation coefficient between the preference score and the performance score was .75 ($p<.001$). When self-classified right- and left-handers were considered separately, the correlation coefficient was greatly reduced because of the restriction of range, .17 ($p<.01$) for the right-handers and .30 ($p<.05$) for the left-handers. Five self-classified left-handers and two self-classified right-handers reported that they wrote with their non-dominant hand. Their non-dominant hand also was better than their dominant hand on the dot-filling test. Their data therefore were excluded from the analysis because of the uncertainty about their handedness classification. By contrast, of the 491 subjects who wrote with their dominant hand, all but 3 were better on the dot-filling test with their dominant hand.

The summary scores on the dot-filling test are shown in Table 30. When all the distributions were examined for normality, not only the entire group but also the right- and left-handers separately showed normal distributions, although with different means (Figure 9). The right-handers, however, showed more lateralized performance than the left-handers ($t(490) = 3.01$, $p<.01$). In other words, hand differences were larger for right-handers than for left-handers. Both the men's and

Table 30

Descriptive Data for the Hand Performance Scores

Group	$\underline{n}$	Mean	SD	Skewness	Kurtosis
Right-hander	430	.226	.082	.357	.440
Left-hander	55	.196	.109	1.591	6.141
Male	243	.220	.084	.559	.984
Female	245	.224	.087	.549	2.420
Male R-hander	217	.223	.083	.624	1.005
Female R-hander	213	.230	.081	.079	-.037
Male L-hander	25	.191	.096	.522	1.179
Female L-hander	30	.201	.121	2.002	7.657

Table 31

Descriptive Data for the Hand Preference Scores

Group	N	Mean	SD	Skewness	Kurtosis
Right-hander	421	210.722	17.259	-.303	.480
Left-hander	56	122.786	38.635	.379	-.614
Male	239	197.084	34.846	-2.023***	4.580
Female	240	203.342	35.464	-1.924***	3.629
Male R-hander	211	207.232	17.117	-.318	.794
Female R-hander	210	214.229	16.721	-.301	.234
Male L-hander	27	120.148	40.102	.158	-.751
Female L-hander	29	125.241	37.759	.677	-.504

*** $\underline{p}<.001$ deviation from normality.

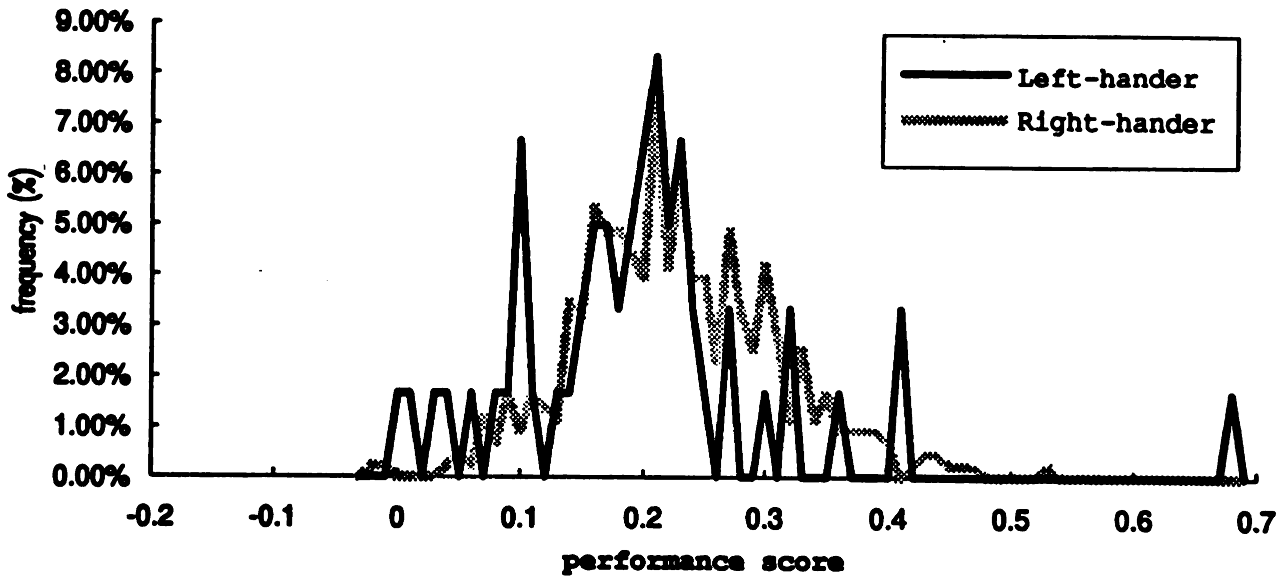

Figure 9. Frequency distributions (percentage of subjects) of performance scores of the right-handers and left-handers. Positive score = dominant hand > non-dominant hand; Negative score = dominant hand < non-dominant hand.

Table 32

Correlation Coefficients between Performance Score and Hand Preference Factors

Factor	Total (N=465)	Right-hander (n=412)	Left-hander (n=51)
1	.841***	.055	--[a]
2	.785***	.194***	.481***
3	.736***	.179***	.314*
4	.415***	.062	.108
5	.393***	-.024	.226
6	.507***	.131**	.199
7	.488***	.169**	.160
8	.517***	.109*	.159
9	.410***	.144**	.145
Total	.754***	.170**	.300*

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

[a] A coefficient cannot be computed.

the women's scores also were distributed normally, and no sex differences were evident.

Although the distribution of the preference data as a whole was highly negatively skewed, the hand preference scores for the right- and the left-handers were each normally distributed (Table 31). The left-handers also were found to be less lateralized than the right-handers as they had been in the performance scores. The distributions of hand preference scores were very skewed in both males and females. Females also were more strongly lateralized than males, with the sex difference significant for the right-handers ($z=2.07$, $p<.001$), but not for the left-handers ($z=.56$, ns).

The correlations between hand performance and each factor of hand preference were computed (Table 32). For the entire group, significant correlations were found between hand performance and all handedness factors. However, for the right-handers 6 of the 9 factors were significantly correlated, compared to only 2 for the left-handers. Only Factors 2 and 3 were significantly correlated with the performance score for both the right- and the left-handers.

Discussion. The high correlation between performance scores and preference scores for the total sample, along with the finding that most subjects perform better with the dominant hand, suggests that hand performance and hand preference draw on a common property of handedness.

These results are consistent with those reported by Tapley and Bryden (1985) and Curt, Maccario, and Dellatolas (1992), who used the same dot-filling test, and by McManus (1985), who used a square-marking task very similar to the dot-filling test. All these studies, along with the current study, found two normal distributions either with positive and negative means or with two positive means,[12] when right-

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[12] Tapley and Bryden's (1985) scoring procedure differed from that of the present study. Tapley and Bryden expressed the performance differences between hands as the right-hand performance score minus the left-hand performance score divided by the total score (R-L / R+L). Therefore, subjects who showed superior test performance with their left

and left-handers were considered separately. Based on their own results, Tapley and Bryden argued that there are two distinct subpopulations of handedness, one essentially left-handed, the other essentially right-handed. They expressed skepticism about studies in which a large group is defined as "mixed" handed (Annett, 1967) or "non-right handed." However, Annett and Kilshaw (1983) found that performance data from their peg-moving test were best fitted by two or three normal distributions, one with a mean of zero and the other(s) with positive mean(s). Such results are predicted from Annett's right-shift model of handedness. This model (Annett, 1985) assumes that there are two groups that possess the right-shift gene (rs^{+}), one of them homozygous (rs^{++}), the other heterozygous (rs^{+-}), and another group not possessing the right-shift gene (rs^{--}). The former group or groups show biased performance toward the right (R>L) with positive mean(s), whereas the latter group lacks a systematic bias to either side and is centered at the neutral point (R=L). Like Tapley and Bryden's and McManus's (1985) data, the present data indicate that the mean of the distribution for the left-handers was not zero, thereby also providing evidence against Annett's model.

It is not clear why one distribution should have a mean of zero for the peg-moving task but not for the dot-filling test. The differences in scoring procedures might be one reason. Annett and Kilshaw's (1983) dependent measure was right and left hand (R-L) difference in performance time for execution of a fixed number of actions, whereas the current study, McManus (1985), and Tapley and Bryden (1985) used a ratio score (D-ND/D+ND or R-L/R+L) to correct for

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hand got negative scores. Tapley and Bryden (1985) found a negative mean score for the left-handers, and a positive mean score for the right-handers. The present study, however, expressed the hand differences as a performance score of the dominant (preferred) hand, regardless of whether it was left or right, minus the performance score of the non-dominant hand divided by the total score (D-ND / D+ND). Positive scores reflected better performance by the dominant hand. For the comparison with Tapley and Bryden's data, the present data were reanalyzed using Tapley and Bryden's scoring method. From this reanalysis, one positive and one negative mean were yielded just as Tapley and Bryden had found.

differences in rate of responding. However, as Tapley and Bryden also suggested, the scoring method alone could not account for the discrepant results because, however the data were scored, a positive or negative ratio score also remained on the positive or negative side of zero in the distribution.

The discrepant results also might stem from differences in what each task measures. The dot-filling test was designed as a group test, gave the subjects a fixed time period, and measured their performance during this interval, whereas the peg-moving test is an individual test and measures the time required to execute a fixed number of actions. In the peg-moving test, subjects move dowels from one set of holes to another. This test was considered to require more precise movement than the dot-filling test because a mark in a circle can be either a tick, overlapping the edge, or a neat dot in the center of the circle, whereas a peg not correctly placed in the hole will fall over (Tapley & Bryden, 1985). However, these differences still do not satisfactorily account for the discrepant results. Many researchers (e.g., Peters & Servos, 1989; Porac & Coren, 1981, Tapley & Bryden, 1985) therefore have suggested that different tests of hand performance measure somewhat different factors. What property of handedness does the dot-filling test measure? In the current study, the significant correlation coefficients between performance score and preference scores of each handedness factor showed that performance on the dot-filling test was significantly correlated with all of the primary hand preference factors for the entire group. For right-handers, significant correlations were found for all factors except Factors 1, 4, and 5. For left-handers (with some reservation because of small sample size), significant correlations were found for Factors 2 ($p<.001$) and 3 ($p<.05$). Only Factors 2 and 3 were significantly correlated with performance scores for both right- and left-handers. Factor 1 showed the highest correlation with performance scores ($r=.84$) for the entire group, although the correlation was not significant for the right-handers, and a correlation could not be computed for the left-handers because of a severely truncated range of responses on the preference questionnaire[13]. This high correlation for Factor 1 is supported by Peters and Servos' (1989) suggestion that the dot-filling test has some elements in common with hand-writing. Therefore, this multifactorial approach shows that the dot-filling test measures a skill related to hand preference for skilled, unimanual activities that do not require much hand strength.

[13] As reported earlier, nearly all right-handers (96.4%) reported that they "always" used their right hand for writing and drawing, and all left-handers reported that they "always" used their left hand. Because of the lack of variations in the preference measure, a significant correlation with the performance score was not found for the right-handers, and the correlation could not be computed for the left-handers.

SUMMARY AND CONCLUSIONS

Is Handedness Unifactorial or Multifactorial?

The present study was designed to assess the factor structure of handedness using phenotypic data from a large and diverse array of activities, and, using the factor structure, to better understand phenotypic variations in handedness. From the confirmatory factor analysis of the comprehensive 71-item Lateral Preference Questionnaire, 9 primary handedness factors emerged. These factors showed the combinations of several of the handedness dimensions found in previous studies, such as skilled versus unskilled, distal versus proximal, unimanual versus bimanual, and degree of strength required. Factor 1 (write-draw) consisted of very skilled, very distal, unimanual acts requiring low to moderate strength. Factor 2 (use-manipulate) consisted of skilled, more distal, unimanual acts requiring low to moderate strength. Factor 3 (throw-shoot) consisted of skilled, more proximal, unimanual acts requiring low to moderate strength. Factor 4 (bat-axe) consisted of skilled, more proximal, bimanual acts requiring high strength. Factor 5 (mop) consisted of less skilled, proximal, bimanual acts requiring low strength. Both Factor 6 (point-touch) and Factor 7 (pick-up) included less skilled, distal, unimanual acts requiring low strength. However, Factor 7 was restricted to "picking-up" acts, whereas Factor 6 included other acts such as waving goodbye and switching on the light. Factor 8 (strength/lift) consisted of less skilled, proximal, unimanual acts requiring high strength. Factor 9 (strength/turn-twist) consisted of less skilled, distal, bimanual acts requiring high strength.

At a superficial level, this primary factor analysis suggests that handedness is multifactorial and that there is no general handedness factor. However, because the primary factors themselves were highly correlated, the possibility arises that there is a general handedness factor that hierarchically includes the primary factors. To find out, factor analysis was applied to the correlations between the primary factors. This hierarchical (second-order) factor analysis yielded 3 second-order handedness factors. Because the acts comprising the second-order factors appeared to differ from each other in the amount of skill required, the factors were named "very skilled," "skilled," and "less skilled." Once again, at a superficial level, this would suggest that handedness is multifactorial. As was true for the primary factors, however, the second-order factors were found to be highly correlated, and also nonlinearly related, consistent again with the assumption of a one-factor model.

In sum, the results indicate that the factor structure of human handedness shows a three-level hierarchy consisting, at the first level, of 9 primary factors, at the second level, of 3 second-order factors, and at the third level, of 1 general handedness factor, as shown in Figure 6 (p. 94). In light of these results, what, then, is the answer to the question, "Is handedness unifactorial or multifactorial?" The answer would depend on the level of the hierarchy on which we choose to focus. Focusing on the general handedness factor would suggest that hand preferences for all kinds of acts are under the influence of a single mechanism. What this mechanism may be remain to seen. When we focus on the second level, we also see that the extent of this influence depends on the amount of skill required to carry out those acts, and that this dimension of handedness (degree of skill, ranging across three levels [FACTORs I, II, III]) was a stronger influence than the other handedness dimension such as distal versus proximal, unimanual versus bimanual, and degree of strength (see Table 1). This does not mean that the other dimensions can be ignored or should not be considered. As mentioned earlier, although the 9 factors identified as primary factors in the confirmatory factor analysis were highly correlated with each other within levels of skill, they were nonetheless distinct. This suggests that within skill levels, the other dimensions influence the determination of hand preference for those acts. As just noted, the current results suggest that the dimensions underlying the primary factors are distal versus proximal, unimanual versus bimanual, and degree of strength.

Therefore, the question, "Is handedness unifactorial or multifactorial?", is not the right question. The better question is, "What does this hierarchical factor structure of handedness tell us about brain lateralization or brain organization?" For example, if there is a single "general handedness" at the top of the hierarchy, and if it implies a single mechanism underlying all aspects of handedness, why is it expressed more strongly for one dimension of handedness than for another? Are there clues in the characteristics of the dimensions themselves as previously described in the current study? These questions still remain to be answered.

Is Lateral Preference Unifactorial or Multifactorial?

The primary factor analysis based on the results of the confirmatory factor analysis of the 71-item Lateral Preference Questionnaire produced three other laterality factors (footedness, earedness, and eyedness) along with the 9 primary handedness factors already mentioned. The second-order factor analysis produced one factor (FACTOR IV) encompassing three other laterality factors along with the three second-order handedness factors already mentioned (FACTORs I, II, III). High correlations between FACTOR IV -- the "other laterality" factor -- and the three second-order handedness factors suggest a general factor underlying all aspects of laterality, or at least all aspects of laterality assessed in this study. The 4 × 4 laterality correlation matrix showed that the factors for the four modalities were themselves highly correlated. A one-factor model showed a perfect fit to the pattern of the intermodality correlations. These results thus suggest that a general laterality factor underlies all lateral preferences, but to different degrees for different modalities. The correlations between the general laterality factor and the four specific laterality factors were .90 for handedness, .82 for footedness, .69 for earedness, and .55 for eyedness.

These results therefore indicate that lateral preference, like handedness itself, is also hierarchical and that handedness is an almost perfect indicator of general laterality.

Can Factor Structure Help to Elucidate Phenotypic Variations in Handedness?

The current study shows that handedness is hierarchical and in part nonlinear. The next question is whether and how these general findings about the factor structure might help us to better understand certain phenotypic variations in handedness. Based on the primary factor analysis, additional comparisons were made between right-handers versus left-handers, males versus females, FS+ subjects versus FS- subjects, hand-change group versus no-change group, and hand preference versus hand performance.

Right-Handers versus Left-Handers

Many earlier studies have reported that left-handers are less consistent than right-handers. This difference was confirmed in the current study, which also revealed that left-handers' weaker lateralization primarily reflected inconsistency between rather than within activities. This suggests that left-handers are as strongly lateralized as right-handers on individual activities but are less consistent in the direction of hand preference. The left-handers showed significant between-item inconsistencies for acts of throwing (Factor 3) and for acts requiring strength (Factors 4, 8, and 9). Recall Peters and Servos' (1989) suggestion that there are two distinct left-handed phenotypes -- consistent left-handers (CLHs) and inconsistent left-handers (ILHs). Recall also that their ILHs favored their left hand for tasks requiring distal, unimanual skills (Factors 1 and 2 in the present study) and their right hand for tasks involving strength or proximal, ballistic acts (Factors 3, 4, 8, and 9 in the present study). Based on the same categorization procedure used by Peters and Servos (1989), 53.6% of the left-handers in the current study were classified as ILHs and 46.4% as CLHs. These results further confirm the existence of these phenotypic subtypes. They also corroborate Peters (1990a) and Snyder and Harris' (1992) estimates that about 50% of population of left-handers is ILH, and 50% CLH. Further analyses also supported Peters and Servos' findings of no differences in consistency (B) between CLHs and right-handers, but also found differences for within as well as between consistency for certain of the 9 primary factors. When consistency (W) was considered, the ILHs proved to be less lateralized than the right-handers for 4 of 9 factors, whereas the CLHs proved to be less lateralized for only one factor. When consistency (B) was considered, the ILHs were less lateralized than the right-handers on 6 factors, whereas the CLHs were less lateralized for only one factor. The ILHs also showed much less between-item consistency than the CLHs.

<u>Sex Differences</u>

In contrast to many previous studies, no differences were found in the percentages of male and female left-handers. Among right-handers, however, females were more strongly right-handed than males, consistent with previous studies. No such differences appeared among left-handers. For purposes of examining sex differences on the factor structure, right- and left-handers were combined. Although the underlying factor structures remained the same across sexes, consistent sex differences were revealed for acts requiring high strength (Factors 4, 8, and 9). For these acts, men showed weaker, less consistent hand preference than women, with men more often than women choosing to use their nondominant hand. This suggests that scores on these strength factors may make the largest contribution to the overall sex differences in hand preference.

Familial Sinistrality

The familial sinistrality data showed significant differences in the prevalence of left-handedness between generations, with left-handedness being most prevalent in the college students, less so in the parents, and least of all in the grandparents. The same data, however, failed to indicate that left-handedness itself "ran in families" inasmuch as the percentages of FS+ and GPFS(grandparent-parent FS)+ were almost equal in right-handers and left-handers. The results also revealed different child-parent patterns based on sex. A higher prevalence of left-handedness in children was found with a right-handed father and left-handed mother than with a left-handed father and right-handed mother, although the difference was only marginally significant. The results, however, failed to show any effects of familial sinistrality on the 9 primary handedness factors. Assuming that the factorial structure based on handedness phenotype scores is capable, in principle, of illuminating underlying genetic mechanisms, the problem in the current study was that the sample sizes were too small in several cases. Finally, the results disclosed small but systematic differences between subjects' reports of parental handedness and parental handedness as reported by the parents themselves. They showed that if the data about parental handedness were based on only the offsprings' reports, 37% of the left-handed parents and 9.1% of the right-handed parents would have been misclassified.

Hand Preference Change

The present data showed that overt attempts to change hand use are common among American college students, but they also show that the vast majority of attempts are designed to achieve ambidextrous skill rather than to substitute one hand for the other. Given that this was the aim in most cases, it is understandable that the comparisons of mean hand preference scores for each factor between the Hand-Change Group and the No-Change Group showed that hand change was mostly incomplete. Even for subjects in the Hand-Change Group who reported that they "successfully changed their handedness" from left to right, analysis of their hand preference scores indicated that, except for writing and drawing (Factor 1), they either remained left-handed or did not reach the same levels of right-handedness for unimanual, skilled behaviors (Factors 2 and 3) as did those right-handers who did not report having undergone attempts to change their hand use.

Hand Preference and Hand Performance

Different tests of hand performance may measure different factors. Previous investigators have supposed that the nature of performance tasks could be revealed by the multifactorial approach to hand preference. The current results support this supposition with respect to the performance measure -- dot-filling test -- included in the current study. The results showed that although the dot-filling test scores were strongly correlated with preference scores for right- and left-handers alike, of the 9 primary handedness factors, only Factors 1, 2, and 3 were significantly correlated with performance scores within both right- and left-hander groups. This suggests that the dot-filling test measures skilled, unimanual acts that do not require much hand strength.

Implications for Future Research

A Short-Form Questionnaire

Despite the common view that different handedness classification methods will yield different prevalence estimates of handedness (Annett, 1985; Bryden, 1977; Peters, 1992), there has been no agreement among researchers about which classification method should be used. As discussed earlier, one of the purposes of identifying the underlying dimensions of handedness is to provide more consistent and theoretically defensible rules for classification of handedness. Although it has been found that particular items may have large effects on laterality quotients and that the factor structure may be very sensitive to item content, researchers who have used factor analysis disagree about what kinds of behavior should be sampled. Thus the choice of items for a handedness questionnaire usually has been arbitrary. The 71-item Lateral Preference Questionnaire used in the current study included 55 handedness items from a very diverse array of activities. From these 55 items, 9 handedness factors were yielded. The results suggest that all 9 categories of behavior should be included in any handedness questionnaire if we are to better understand the multifaceted nature of handedness. Of course, it would be difficult, sometimes even impossible, to administer a long questionnaire to certain subjects (e.g., young children, clinical patients). Therefore, a short-form questionnaire should be developed for these subjects. The current results suggest that the items for this questionnaire should sample from all 9 factors. The question how many and which items should be selected from each factor still remain to be answered.

Factorial Approach with Other Populations

If handedness seems simple, it looks very complex when examined closely. Its phenotypic expression appears to be influenced not only by genetic or physiological factors but also by social or cultural factors, all working in complicated interaction. Therefore, the first step for studying handedness should be the full exploration of diverse handedness behaviors. The current study has shown that the factorial approach to the study of handedness, using phenotypic data from a large number of diverse behaviors, provides important information that helps us to better understand phenotypic variations in handedness. The current study, however, was done with college students. The results now need to be compared with data from other populations. For example, unlike adults, infants and children are undergoing rapid changes in many underlying capacities and behaviors. Michel, Ovrut and Harkins (1986) found that although a population bias towards right-handedness can be observed in children as young as 6 months of age, the proportion of infants showing hand preferences was lower than in older infants (13 months of age), and those preferences, in turn, were less stable and less consistent than in adults. In young children, choice of hand to perform a skilled action also is more subject to temporary situational influences than it is in older children (Bruml, 1972). Bishop (1990) argued that the major aspect of laterality that changes with age is stability of hand preference for a given activity across different occasions. Tupper (1983) found that, for the tests of unilateral motor skill, about 80% of 3- to 8-year-olds show consistent right-hand use, with little age change in side, degree, or pattern of lateral preference. These data suggest that only by about 3 to 4 years of age will children show fairly reliable hand use and skill. Steenhuis et al. (1990) reported finding the same general factor structure in 9- to 14-year-olds as in adults and, from this, argued that the factor structure of handedness is stable across age. Considering Tupper's findings, however, 9- to 14-year-olds are probably too old to reveal any instability, assuming it is there. Therefore, we might expect that data for younger children (e.g., preschool children) would show a different or weak handedness factor structure. The current study also tested American college students, who were not expected to have been the objects of significant social pressure in relation to hand preference. Use of the factorial approach with populations from cultures who still experience strong social pressure relating to hand use therefore could provide important further information about handedness. A study of this sort is under way for a sample of Korean college students. Finally, the current study was done with a normal population. Applying factor analysis to handedness data from clinical populations, such as apraxics or other patients with lateralized lesions, might contribute to our understanding of movement dysfunction. By such further attention to handedness phenotype, we may be able to significantly advance our understanding of brain lateralization and to find more theoretically-based rules for categorization of handedness groups.

An adequate theory of handedness should account not only for the facts of lateralization but also for the relationship between lateral specialization and those particular handedness categories that are included in hand preference and performance measures. The present findings show that the factor analytic approach offers a means of meeting this goal. They also should encourage further analysis into handedness phenotype.

APPENDICES

APPENDIX A

STUDENTS' QUESTIONNAIRES

Dear Student:

Recent scientific studies have revealed a number of interesting things about handedness. There is still a great deal, however, that we do not know. For example, do people always use the same hand to write a letter as they use to pick up a dime on the ground? Can left-handers be changed to right-handers by training? Is handedness inherited from parents? In addition to hand preference, do people also have preferences for using one ear, one eye, or one foot?

We are studying these and other questions by means of the attached questionnaires. The questionnaires will take approximately 1 hour to complete. You will receive 2 credits for the time you spend in this study, and the credits will be translated into class credits in your psychology class. We cannot guarantee that you will receive any personal and direct benefits from participating in this research. You will, however, be contributing to our fundamental scientific understanding of handedness. You also might even discover some interesting things about your own handedness. You indicate your voluntary agreement to participate by completing and returning this questionnaire. If, after starting, you feel uncomfortable about participating in the study, you have the right to discontinue your participation. You do not have to explain why you want to stop, and you are not penalized for leaving.

The information that you provide will be strictly confidential. You will not be identified in any way by name in any scientific reports that we might prepare. Information on individuals will be identified only by numbers. If you have any questions or concerns about participating in this study, please feel free to ask us. At your request, we can give additional explanation of the study after your participation is completed. Thank you.

Yeonwook Kang,
Doctoral Candidate in Psychology

Lauren Julius Harris,
Professor

Subject Number ___________

PERSONAL DATA QUESTIONNAIRE

1. Birth date: _____/______/______ Age: ___________

2. Sex: male ________ female________

3. Academic major: ____________________

4. Which description applies to you?

a. African-American
b. Asian-American
c. Caucasian
d. Hispanic
e. Native-American
f. Pacific-American
g. Other _____________

5. Were you born in the U.S.? Yes ______ No ______

If no, where were you born? ____________________________

How old were you when you came to the U.S.? _____ years of age

6. With which hand do you write? Left _____ Right _____ Either hand _____

7. Which description best applies to you?

a. Right-handed and strongly so
b. Right-handed but only moderately so
c. Left-handed but only moderately so
d. Left-handed and strongly so.

8. Did you attend a parochial school? Yes ______ No ______

If yes, when did you attend? Please circle all of those that apply to you.

a. Kindergarten
b. Elementary school
c. Junior high school
d. Senior high school

9. What is your father's educational level?

a. Elementary school diploma
b. Some high school
c. High school diploma
d. Some college
e. Bachelor's degree
f. Some graduate training or more

(continued on next page)

10. What is your mother's educational level?

    a. Elementary school diploma
    b. Some high school
    c. High school diploma
    d. Some college
    e. Bachelor's degree
    f. Some graduate training or more

11. What is your father's occupation? ______________________________

12. What is your mother's occupation? ______________________________

LATERAL PREFERENCE QUESTIONNAIRE

The following questions ask you about your preference for use of one or the other hand, foot, ear, and eye in a variety of tasks or situations. For each question, please check the category that most accurately describes your use. If you are not sure, perform the action now to make sure by mimicking the movement you would use, or close your eyes and imagine that you are performing the movement. Because your use of a particular hand, foot, eye, or ear may differ from action to action, carefully consider your answer to each question separately. Please be sure to answer every question.

WHICH <u>HAND</u> WOULD YOU USE TO:	always left	usually left	either	usually right	always right
1. write a letter	____	____	____	____	____
2. draw a picture	____	____	____	____	____
3. hold scissors when cutting paper	____	____	____	____	____
4. hold a toothbrush when cleaning your teeth	____	____	____	____	____
5. hold a spoon when eating soup	____	____	____	____	____
6. hold a needle when sewing	____	____	____	____	____
7. hold a hammer when hammering a nail	____	____	____	____	____
8. hold a knife when slicing bread	____	____	____	____	____
9. hold a screwdriver to tighten a screw	____	____	____	____	____
10. hold eraser when erasing pencil marks	____	____	____	____	____

WHICH <u>FOOT</u> WOULD YOU USE TO:	always left	usually left	either	usually right	always right
11. kick a soccer ball into a goalpost	___	___	___	___	___
12. put up on the stool first when you step on a stool	___	___	___	___	___
13. pick up a pebble with your toes	___	___	___	___	___
14. hop on	___	___	___	___	___
15. stand on if you wanted to balance on one leg for the longest time possible	___	___	___	___	___

WHICH <u>HAND</u> WOULD YOU USE TO:	always left	usually left	either	usually right	alway right
16. throw a small ball overhand to hit a target	___	___	___	___	___
17. shoot a marble	___	___	___	___	___
18. roll a bowling ball	___	___	___	___	___
19. throw a dart at a dartboard	___	___	___	___	___
20. hit a volleyball for the serve	___	___	___	___	___
21. play table tennis (ping-pong)	___	___	___	___	___
22. hold a tennis racket (or badminton, or racket ball racket)	___	___	___	___	___
23. bounce a basketball	___	___	___	___	___
24. catch a baseball with one hand without a mitt	___	___	___	___	___
25. throw a Frisbee	___	___	___	___	___

WHICH **EAR** WOULD YOU USE TO:	always left	usually left	either	usually right	always right
26. listen to a conversation behind a closed door	____	____	____	____	____
27. listen to someone's heartbeat	____	____	____	____	____
28. listen to the radio through a single earphone	____	____	____	____	____
29. turn toward a soft sound coming from far away	____	____	____	____	____

WHICH **HAND** WOULD YOU USE TO:	always left	usually left	either	usually right	always right
30. flip a coin	____	____	____	____	____
31. wave goodbye	____	____	____	____	____
32. point to a distant object	____	____	____	____	____
33. knock on someone's door	____	____	____	____	____
34. take a small object that someone is offering to you	____	____	____	____	____
35. make a call (enter the digits) on a push button telephone	____	____	____	____	____
36. snap fingers	____	____	____	____	____
37. switch on the light	____	____	____	____	____
38. operate a doorbell	____	____	____	____	____
39. hold and use a salt shaker	____	____	____	____	____

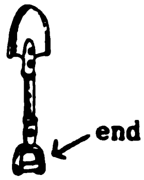
WHICH **EYE** WOULD YOU USE TO:	always left	usually left	either	usually right	always right
40. peep through a keyhole	____	____	____	____	____
41. look into a dark bottle to see how full it is	____	____	____	____	____
42. sight down a rifle when taking aim	____	____	____	____	____
43. look through a telescope	____	____	____	____	____

	always left	usually left	either	usually right	always right
44. aim a camera	____	____	____	____	____
45. thread a needle (that is, which eye would you keep open while aiming the thread through the needle)	____	____	____	____	____
46. look into a microscope	____	____	____	____	____

WHEN YOU PICK UP AN OBJECT, WHICH <u>HAND</u> WOULD YOU USE TO:	always left	usually left	either	usually right	always right
47. pick up a piece of paper	____	____	____	____	____
48. pick up a wallet or purse	____	____	____	____	____
49. pick up a baseball	____	____	____	____	____
50. pick up a marble	____	____	____	____	____
51. pick up a jar	____	____	____	____	____
52. pick up a dime	____	____	____	____	____
53. pick up a paperback book	____	____	____	____	____
54. pick up a paperclip	____	____	____	____	____
55. pick up a glass of water	____	____	____	____	____
56. pick up a straight pin	____	____	____	____	____

IF BOTH HANDS ARE FREE, WHICH <u>HAND</u> WOULD YOU USE TO:	always left	usually left	either	usually right	always right
57. pick up a heavy suitcase to see how heavy it is	____	____	____	____	____
58. carry a briefcase full of books	____	____	____	____	____
59. hold an open umbrella when walking in the rain	____	____	____	____	____
60. carry a bucketful of water	____	____	____	____	____
61. carry a heavy suitcase	____	____	____	____	____

WHICH <u>HAND</u> IS CLOSER TO THE END:



	always left	usually left	either	usually right	always right
62. when using a spade or shovel	____	____	____	____	____
63. when sweeping the floor with a broom	____	____	____	____	____
64. when cleaning the floor with a mop	____	____	____	____	____

WHICH <u>SHOULDER</u> WOULD YOU:	always left	usually left	either	usually right	always right
65. rest a baseball bat on before swinging	____	____	____	____	____
66. swing an axe over	____	____	____	____	____

WHICH <u>HAND</u> WOULD YOU USE TO:	always left	usually left	either	usually right	always right
67. open a can of soda	____	____	____	____	____
68. hold a heavy object	____	____	____	____	____
69. unscrew a tight jar cap	____	____	____	____	____
70. screw the top on a bottle	____	____	____	____	____
71. perform any task requiring strength but allowing for use of only one hand	____	____	____	____	____

DO YOU NOW SUFFER, OR HAVE YOU EVER SUFFERED, FROM ANY PHYSICAL OR OTHER HANDICAP(S) THAT MIGHT HAVE INFLUENCED YOUR ANSWER TO ANY OF THESE QUESTIONS?

Yes __________ No __________

If yes, what is it? ____

____

Which answers (or general category(ies) of answers) were affected?

____

____

HAND PREFERENCE CHANGE QUESTIONNAIRE

The following questions ask about any experiences you might have had pertaining to attempts to change your handedness or to change use of your preferred hand for any particular task(s). Please be sure to answer every question.

---

1. To the best of your knowledge, have any of the persons listed below ever tried to affect your handedness? If so, which hand use for any particular task(s) did the person(s) try to affect? Please circle all of those persons who tried, and describe the handedness behavior(s) that they tried to affect. Circle alternative 1 if no attempt has ever been made to change your handedness.

   a. You (Yourself) ______________________________

   b. Mother ______________________________

   c. Father ______________________________

   d. Brother(s) ______________________________

   e. Sister(s) ______________________________

   f. Grandparent(s) ______________________________

   g. Other relative(s) ______________________________

   h. Teacher(s) ______________________________

   i. Friend(s) ______________________________

   j. Employer ______________________________

   k. Someone else (if so, who?) ______________________________

   l. No one, including myself, has ever tried to affect my handedness.

If you circled any of the person(s) listed above (answers a-k), please answer the remaining questions. When answering each question, circle the one alternative that best describes your situation. If you circled alternative 1, then go to p.12.

(continued on next page)

2. What type of attempt was made to change your handedness?

   a. Change from exclusive right-hand use to exclusive left-hand use.
   b. Change from exclusive right-hand use to ambidexterity (the use of both hands equally).
   c. Change from exclusive left-hand use to exclusive right-hand use.
   d. Change from exclusive left-hand use to ambidexterity (the use of both hands equally).
   e. Change from ambidexterity to the exclusive use of the right hand.
   f. Change from ambidexterity to the exclusive use of the left hand.

3. When was the <u>first</u> attempt made to change your handedness?

   a. Before you started primary school.
   b. In grades 1 to 3.
   c. In grades 4 to 6.
   d. After grade 6.

4. When was the <u>last</u> attempt made to change your handedness?

   a. Before you started primary school.
   b. In grades 1 to 3.
   c. In grades 4 to 6.
   d. After grade 6.

5. Was the attempt to change your handedness successful?

   a. Very successful
   b. Moderately successful
   c. Moderately unsuccessful
   d. Very unsuccessful

6. If the change was either very successful or moderately successful (answer a or b), when was the change accomplished?

   a. Before you started primary school.
   b. In grades 1 to 3.
   c. In grades 4 to 6.
   d. After grade 6.

7. Of all of the different persons (including yourself) who might have played a role in trying to change your handedness, which one person do you think was the most effective or influential?

   a. You, yourself
   b. Mother
   c. Father
   d. Brother
   e. Sister
   f. Grandparent
   g. Other relative ____________________
   h. Teacher
   i. Friend
   j. Employer
   k. Someone else (if so, who?) ___________

(continued on next page)

8. Which handedness behavior(s) did the person named above try to change <u>most</u> actively?

    a. Writing
    b. Eating
    c. Sports
    d. Other____

9. Why did this person want to change your handedness?

____

____

____

____

10. Describe, in as much detail as you can recall, how this person tried to change your handedness.

____

____

____

____

____

FAMILY HANDEDNESS QUESTIONNAIRE

The following questions ask about the handedness of members of your family. For all questions, we are interested in only those relatives who are related to you biologically.

---

1. Writing hand: What is the writing hand of your:

	left	either	right	unknown
mother	____	____	____	____
maternal grandfather	____	____	____	____
maternal grandmother	____	____	____	____
father	____	____	____	____
paternal grandfather	____	____	____	____
paternal grandmother	____	____	____	____

2. General handedness: In consideration of the large range of skilled tasks (like those you have already been asked about) for which one hand may be used preferentially, how would you characterize the general handedness of your relatives? It need not necessarily be the same as the hand used for writing.

	left	either	right	unknown
mother	____	____	____	____
maternal grandfather	____	____	____	____
maternal grandmother	____	____	____	____
father	____	____	____	____
paternal grandfather	____	____	____	____
paternal grandmother	____	____	____	____

(continued on next page)

3. If you have any brothers or sisters, please list their age, sex (M for male; F for female), writing hand and handedness.

			writing hand				handedness			
	age	sex	left	either	right	unknown	left	either	right	unknown
# 1.	____	____	____	____	____	____	____	____	____	____
# 2.	____	____	____	____	____	____	____	____	____	____
# 3.	____	____	____	____	____	____	____	____	____	____
# 4.	____	____	____	____	____	____	____	____	____	____
# 5.	____	____	____	____	____	____	____	____	____	____
# 6.	____	____	____	____	____	____	____	____	____	____
# 7.	____	____	____	____	____	____	____	____	____	____
# 8.	____	____	____	____	____	____	____	____	____	____
# 9.	____	____	____	____	____	____	____	____	____	____
#10.	____	____	____	____	____	____	____	____	____	____

4. To the best of your knowledge, has anyone among your parents, siblings, and grandparents ever been forced to change their preferred hand for either social or physical reasons? If so, describe the reasons, the direction of change, and the age at which the change was made.

who	reasons / direction / age
______________	____
______________	____
______________	____
______________	____

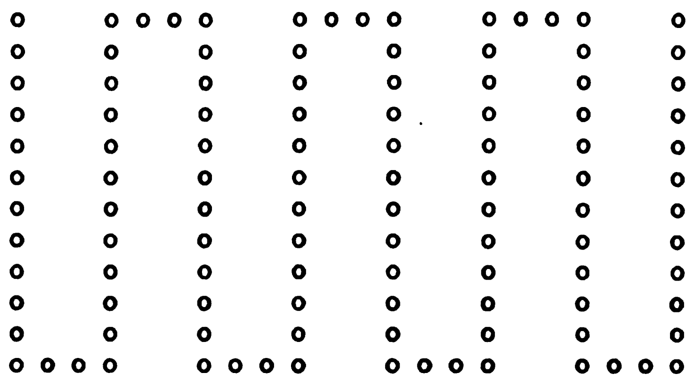
END OF QUESTIONNAIRE

PLEASE WAIT FOR FURTHER INSTRUCTIONS.

DOT-FILLING TEST

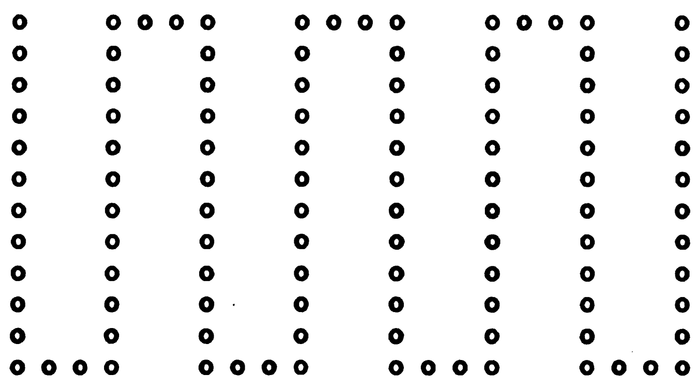
1. Use the hand you write with.

Start here →



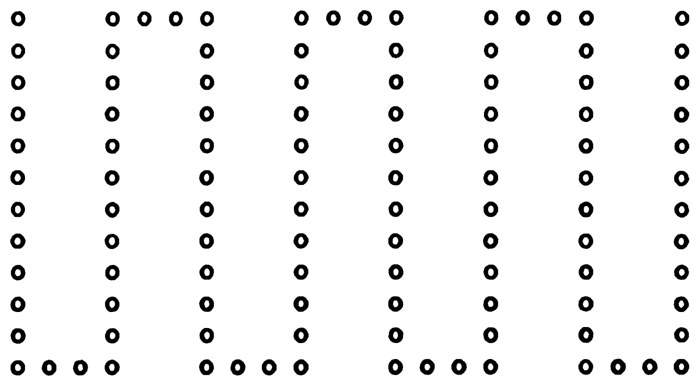
2. Use the hand you do <u>not</u> write with.

Start here →



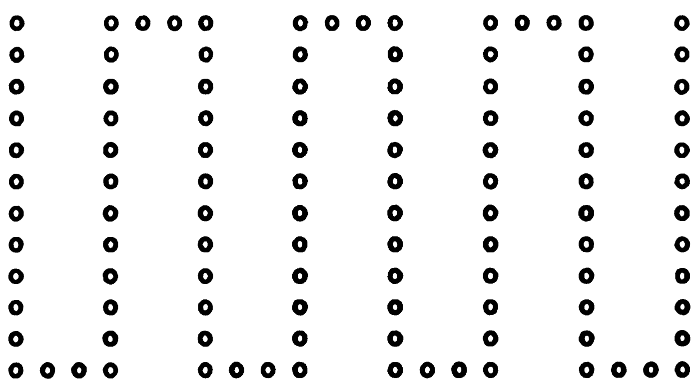
3. Use the hand you do <u>not</u> write with.

Start here →



4. Use the hand you write with.

Start here →



APPENDIX B

PARENTS' QUESTIONNAIRES

Parents' Questionnaires

Dear Student:

An important part of this study has been to obtain information about the handedness of your relatives (e.g., your parents). From our own experiences, we realize that it may not have been easy for you to provide accurate information about the handedness of your relatives. Therefore, to make sure that this information is accurate, we would like to be able to ask your parents for this information directly. To do this, we need your help. We have written a letter to your parents soliciting their participation. The letter is on the next page. We also have attached the questionnaire for your parents to answer. If you will allow us to send the questionnaire to your parents, please write your parents' names and address(es) on the attached envelope. The information from your parents will be strictly confidential and will be identified only by numbers assigned to their questionnaire for pairing with your questionnaires. Thank you.

Please note: The parental questionnaires are only for those of you whose parents did not divorce and who lived together with you at least until you reached the age of 8 years.

MICHIGAN STATE UNIVERSITY

DEPARTMENT OF PSYCHOLOGY
PSYCHOLOGY RESEARCH BUILDING

EAST LANSING · MICHIGAN · 48824-1117

May 1, 1991

Dear Parent(s):

We are psychologists engaged in a study of the relationship between the handedness of parents and their children. The study has been formally approved by the Human Subject Committee in Michigan State University. Your son or daughter has already participated in this study and has answered questions about his or her own handedness as well as questions about your handedness. We recognize, however, that even children of college age may not necessarily be able to give accurate information about their parents' handedness. Therefore, we would like to ask you for this information directly. We also have included questions about lateral preferences for use of feet, eyes, and ears.

Of course, we received your name(s) and address from your child following his or her participation. Like your child, you are under no obligation to participate in this study. It is strictly voluntary. You will indicate your voluntary agreement to participate by completing and returning these questionnaires. There are two questionnaires - one to be filled out by the mother, the other by the father. The information will be confidential. You will not be identified in any way by name in any scientific reports that we might prepare. Information on individuals will be identified only by number that is assigned to your questionnaire for pairing with your child's.

If you choose to participate, each questionnaire will take approximately ten minutes to complete. The completed questionnaires should be returned to us in the enclosed self-addressed envelope. We hope that this can be done as soon as possible. If you have any questions about the study or about your participation, feel free to call us at (517) 355-3950 or 353-0792. Thank you for your time and consideration.

Sincerely yours,

Yeonwook Kang,
Doctoral Candidate in Psychology

Lauren Julius Harris,
Professor

Subject Number ___________

(FATHER)

LATERAL PREFERENCE QUESTIONNAIRE

The following questions ask you about your preference for use of one or the other hand, foot, ear, and eye in a variety of tasks or situations. For each question, please check the category that most accurately describes your use. If you are not sure, perform the action now to make sure by mimicking the movement you would use, or close your eyes and imagine that you are performing the movement. Because your use of a particular hand, foot, eye, or ear may differ from action to action, carefully consider your answer to each question separately. Please be sure to answer every question.

WHICH <u>HAND</u> WOULD YOU USE TO:	always left	usually left	either	usually right	always right
1. write a letter	____	____	____	____	____
2. draw a picture	____	____	____	____	____
3. hold scissors when cutting paper	____	____	____	____	____
4. hold a toothbrush when cleaning your teeth	____	____	____	____	____
5. hold a spoon when eating soup	____	____	____	____	____
6. hold a needle when sewing	____	____	____	____	____
7. hold a hammer when hammering a nail	____	____	____	____	____
8. hold a knife when slicing bread	____	____	____	____	____
9. hold a screwdriver to tighten a screw	____	____	____	____	____
10. hold eraser when erasing pencil marks	____	____	____	____	____

WHICH <u>FOOT</u> WOULD YOU USE TO:	always left	usually left	either	usually right	always right
11. kick a soccer ball into a goalpost	____	____	____	____	____
12. put up on the stool first when you step on a stool	____	____	____	____	____
13. pick up a pebble with your toes	____	____	____	____	____

	always left	usually left	either	usually right	always right
14. hop on	____	____	____	____	____
15. stand on if you wanted to balance on one leg for the longest time possible	____	____	____	____	____

WHICH EYE WOULD YOU USE TO:	always left	usually left	either	usually right	always right
16. peep through a keyhole	____	____	____	____	____
17. look into a dark bottle to see how full it is	____	____	____	____	____
18. sight down a rifle when taking aim	____	____	____	____	____
19. look through a telescope	____	____	____	____	____
20. aim a camera	____	____	____	____	____
21. thread a needle (that is, which eye would you keep open while aiming the thread through the needle)	____	____	____	____	____
22. look into a microscope	____	____	____	____	____

WHICH EAR WOULD YOU USE TO:	always left	usually left	either	usually right	always right
23. listen to a conversation behind a closed door	____	____	____	____	____
24. listen to someone's heartbeat	____	____	____	____	____
25. listen to the radio through a single earphone	____	____	____	____	____
26. turn toward a soft sound coming from far away	____	____	____	____	____

DO YOU NOW SUFFER, OR HAVE YOU EVER SUFFERED, FROM ANY PHYSICAL OR OTHER HANDICAP(S) THAT MIGHT HAVE INFLUENCED YOUR ANSWER TO ANY OF THESE QUESTIONS?

Yes ________ No ________

If you answered yes, please explain the circumstances. ____________________

____

(MOTHER) Subject Number __________

LATERAL PREFERENCE QUESTIONNAIRE

The following questions ask you about your preference for use of one or the other hand, foot, ear, and eye in a variety of tasks or situations. For each question, please check the category that most accurately describes your use. If you are not sure, perform the action now to make sure by mimicking the movement you would use, or close your eyes and imagine that you are performing the movement. Because your use of a particular hand, foot, eye, or ear may differ from action to action, carefully consider your answer to each question separately. Please be sure to answer every question.

WHICH <u>HAND</u> WOULD YOU USE TO:	always left	usually left	either	usually right	always right
1. write a letter	____	____	____	____	____
2. draw a picture	____	____	____	____	____
3. hold scissors when cutting paper	____	____	____	____	____
4. hold a toothbrush when cleaning your teeth	____	____	____	____	____
5. hold a spoon when eating soup	____	____	____	____	____
6. hold a needle when sewing	____	____	____	____	____
7. hold a hammer when hammering a nail	____	____	____	____	____
8. hold a knife when slicing bread	____	____	____	____	____
9. hold a screwdriver to tighten a screw	____	____	____	____	____
10. hold eraser when erasing pencil marks	____	____	____	____	____

WHICH <u>FOOT</u> WOULD YOU USE TO:	always left	usually left	either	usually right	always right
11. kick a soccer ball into a goalpost	____	____	____	____	____
12. put up on the stool first when you step on a stool	____	____	____	____	____

	always left	usually left	either	usually right	always right
13. pick up a pebble with your toes	____	____	____	____	____
14. hop on	____	____	____	____	____
15. stand on if you wanted to balance on one leg for the longest time possible	____	____	____	____	____

WHICH <u>EYE</u> WOULD YOU USE TO:	always left	usually left	either	usually right	always right
16. peep through a keyhole	____	____	____	____	____
17. look into a dark bottle to see how full it is	____	____	____	____	____
18. sight down a rifle when taking aim	____	____	____	____	____
19. look through a telescope	____	____	____	____	____
20. aim a camera	____	____	____	____	____
21. thread a needle (that is, which eye would you keep open while aiming the thread through the needle)	____	____	____	____	____
22. look into a microscope	____	____	____	____	____

WHICH <u>EAR</u> WOULD YOU USE TO:	always left	usually left	either	usually right	always right
23. listen to a conversation behind a closed door	____	____	____	____	____
24. listen to someone's heartbeat	____	____	____	____	____
25. listen to the radio through a single earphone	____	____	____	____	____
26. turn toward a soft sound coming from far away	____	____	____	____	____

DO YOU NOW SUFFER, OR HAVE YOU EVER SUFFERED, FROM ANY PHYSICAL OR OTHER HANDICAP(S) THAT MIGHT HAVE INFLUENCED YOUR ANSWER TO ANY OF THESE QUESTIONS?

Yes ________ No ________

If you answered <u>yes</u>, please explain the circumstances. ____________________________

____

LIST OF REFERENCES

LIST OF REFERENCES

Andrews, R. J. (1977). Aspects of language lateralization correlated with familial handedness. Neuropsychologia, 15, 769-778.

Annett, M. (1967). The binomial distribution of right, mixed, and left handedness. Quarterly Journal of Experimental Psychology, 19, 327-333.

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

Annett, M. (1970b). The growth of manual preference and speed. British Journal of Psychology, 61, 545-558.

Annett, M. (1972). The distribution of manual asymmetry. British Journal of Psychology, 63, 343-358.

Annett, M. (1973). Handedness in families. Annals of Human Genetics, 37, 93- 105.

Annett, M. (1976). A coordination of hand preference and skill replicated. British Journal of Psychology, 67, 587-592.

Annett, M. (1978). Genetic and nongenetic influences on handedness. Behavior Genetics, 8, 227-249.

Annett, M. (1979). Family handedness in three generations predicted by the right shift theory. Annals of Human Genetics, 42, 479-491.

Annett, M. (1985). Left, right, hand and brain: The right shift theory. New York: Lawrence Erlbaum Associates.

Annett, M. & Kilshaw, D. (1983). Right- and left-hand skill II: Estimating the parameters of the distribution of left-right differences in males and females. British Journal of Psychology, 24, 269-283.

Annett, M., & Turner, A. (1974). Laterality and the growth of intellectual abilities. British Journal of Educational Psychology, 44, 37-46.

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

Ardila, A., Ardila, O., Bryden, M. P., Ostrovsky, F., Rosselli, M., & Steenhuis, R. (1989). Effects of cultural background and education on handedness. Neuropsychologia, 27, 893-897.

Ashton, G. C. (1982). Handedness: An alternative hypothesis. Behavior Genetics, 12, 125-147.

Barnsley, R. H., & Rabinovitch, M. S. (1970). Handedness: Proficiency versus stated preference. Perceptual and Motor Skills, 30, 343-362.

Barry, H., Bacon, M. K., & Child, I. L. (1957). A cross-cultural survey of some sex differences in socialization. Journal of Abnormal and Social Psychology, 55, 327-332.

Beaumont, J. G., & Rugg, M. D. (1978). Neuropsychological laterality of function and dyslexia: A new hypothesis. Dyslexia Review, 1, 18-21.

Benton, A. L., Meyers, R., & Polder, G. J. (1962). Some aspects of handedness. Psychiatry and Neurology, 144, 321-337.

Beukelaar, L. J., & Kroonenberg, P. M. (1983). Towards a conceptualization of hand preference. British Journal of Psychology, 74, 33-45.

Bishop, D. V. M. (1980). Measuring familial sinistrality. Cortex, 16, 311-313.

Bishop, D. V. M. (1989). Does hand proficiency determine hand preference? British Journal of Psychology, 80, 191-199.

Bishop, D. V. M. (1990). Handedness and developmental disorder. London: MacKeith Press and Blackwell Scientific.

Boller, G., & Green, E. (1972). Comprehension in severe aphasia. Cortex, 8, 382-394.

Borod, J. C., Caron, H. S., & Koff, E. (1984). Left-handers and right-handers compared on performance and preference measures of lateral dominance. British Journal of Psychology, 75, 177-186.

Brackenridge, C. J. (1981). Secular variation in handedness over ninety years. Neuropsychologia, 19, 459-462.

Bradshaw, J. L., & Nettleton, N. C. (1981). The nature of hemispheric specialization in man. The Behavioral and Brain Sciences, 4, 51-91.

Brain, J. L. (1977). Handedness in Tanzania: The physiological aspect. Anthropos, 72, 180-192.

Briggs, G. G., & Nebes, R. D. (1975). The effects of handedness family history and sex on the performance of a dichotic listening task. Neuropsychologia, 14, 129-134.

Brito, G. N. O., Brito, L. S. O., Paumagartten, F. J. R., & Lins, M. F. C. (1989). Lateral preferences in Brazilian adults: An Analysis with the Edinburgh Inventory. Cortex, 25, 403-415.

Brodal, A. (1973). Self-observations and neuroanatomical considerations after a stroke. Brain, 96, 675-594.

Bruml, H. (1972). Age changes in preference and skill measures of handedness. Perceptual and Motor Skills, 34, 3-14.

Bryden, M. P. (1965). Tachistoscopic recognition, handedness and cerebral dominance. Neuropsychologia, 3, 1-8.

Bryden, M. P. (1977). Measuring handedness with questionnaire. Neuropsychologia, 13, 617-624.

Bryden, M. P. (1979). Evidence for sex-related differences in cerebral organization. In M. Wittig & A. C. Petersen (Eds.), Sex-related differences in cognitive functioning: Developmental Issues (pp. 121-143). New York: Academic Press.

Carlson, D. F., & Harris, L. J. (1985). Development of the infant's hand preference for visually directed reaching: Preliminary report of a longitudinal study. Infant Mental Health Journal, 6, 158-172.

Carrothers, G. E. (1947). Left-handedness among school pupils. School Board Journal, 114, 17-19.

Carter-Saltzman, L. (1980). Biological and sociocultural effects on handedness: Comparison between biological and adoptive families. Science, 209, 1263-1265.

Cattell, R. B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. Journal of Educational Psychology, 54, 1-22.

Chamberlain, H. D. (1928). The inheritance of left handedness. Journal of Heredity, 19, 557-559.

Chapman, L. J., & Chapman, J. P. (1987). The measurement of handedness. Brain and Cognition, 6, 175-183.

Chapman, J. P., Chapman, L. J., & Allen, J. J. (1987). The measurement of foot preference. Neuropsychologia, 25, 579-584.

Clark, M. M. (1957). Left-handedness: Laterality characteristics and their educational implication. London: University of London Press.

Collins, R. L. (1977). Toward an admissable genetic model for the inheritance of degree and direction of asymmetry. In S. Harnard, R. W. Doty, J. Jaynes, L. Goldstein, & G. Krauthamer (Eds.), Lateralization in the nervous system (pp. 137-150). New York: Academic Press.

Collins, R. L. (1978). In the beginning was the asymmetry gradient even when it was null: A propositional framework for a general theory of the inheritance of asymmetry. The Behavioral and Brain Sciences, 2, 290-291.

Connolly, K. J., & Bishop, D. V. M. (1992). The measurement of handedness: A cross-cultural comparison of samples from England and Papua New Guinea. Neuropsychologia, 30, 13-26.

Coren, S., & Kaplan, C. P. (1973). Patterns of ocular dominance. American Journal of Optometry and Archives of the American Academy of Optometry, 50, 283-292.

Coren, S., & Porac, C. (1978). The validity and reliability of self-report items for the measurement of lateral preference. British Journal of Psychology, 69, 207-211.

Crovitz, H. F., & Zener, K. (1962). A group-test for assessing hand and eye dominances. American Journal of Psychology, 75, 271-276.

Curt, F., Maccario, J., & Dellatolas, G. (1992). Distributions of hand preference and hand skill asymmetry in preschool children: Theoretical implications. Neuropsychologia, 30, 27-34.

Dawson, J. L. M. (1972). Temne-Arunta hand-eye dominance and cognitive style. International Journal of Psychology, 7, 219-233.

Dawson, J. L. M. (1977). Anthropological perspective on the evolution and lateralization of the brain. In S. J. Diamond & D. A. Blizard (Eds.), Evolution and lateralization of the brain. Annals of the New York Academy of Sciences, 299, 424-447.

Dean, R. S. (1978a). Lateral preference schedule. Odessa, Flor.: Psychological Assessment Resources, Inc.

Dean, R. S. (1978b). Cerebral laterality and reading comprehension. Neuropsychologia, 16, 633-636.

Dean, R. S. (1982). Assessing patterns of lateral preference. Clinical Neuropsychology, 3, 22-28.

Dean, R. S. (1986). Lateralization of cerebral function. In D. Wedding, A. M. Horton, & J. Webster (Eds.), The neuropsychology handbook (pp. 80-102). New York: Springer.

Dean, R. S., Schwartz, N. H., & Smith, L. S. (1981). Lateral preference patterns as a discriminator of learning difficulties. Journal of Consulting and Clinical Psychology, 49, 227-235.

Dean, R. S., Rattan, G., Hua, M. S. (1987). Patterns of lateral preference: An American-Chinese comparison. Neuropsychologia, 25, 585-588.

Ellis, S. J., Ellis, P. J., & Marshall, E. (1988). Hand preference in a normal population. Cortex, 24, 157-163.

Etaugh, C., & Brausam, M. (1978). Sensitivity to laterality as a function of handedness. Perceptual and Motor Skills, 46, 420-422.

Falek, A. (1959). Handedness: A family study. American Journal of Human Genetics, 11, 52-62.

Finlayson, A. J., & Reitan, R. M. (1976). Handedness in relation to measures of motor and tactile-perceptual functions in normal children. Perceptual and Motor Skills, 43, 475-481.

Fitzgerald, H. E., Harris, L. J., Barnes, C. L., Wang, X., Cornwell, K. S., Kamptner, N. L., Dagenbach, D., & Carlson, D. (1991). The organization of lateralized behavior during infancy. In H. E. Fitzgerald, B. M. Lester, & M. W. Yogman (Eds.), Theory and research in behavioral pediatrics (pp. 155-184). (Vol. 5). New York: Plenum.

Fleischman, E. A. (1972). On the relation between abilities, learning, and human performance. American Psychologist, 27, 1017-1032.

Geschwind, N. (1975). The apraxias. American Scientist, 63, 188-195.

Geschwind, N., & Behan, P. (1982). Left-handedness: Association with immune disease, migraine, and developmental learning disorder. Proceedings of the National Academy of Science, 79, 5097-5100.

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

Goodale, M. A. (1987). Two hemispheres: One reaching hand. The Behavioral and Brain Sciences, 10, 275-276.

Guilford, J. P. (1985). The structure-of-intellectual model. In B. B. Wolman (Ed.), Handbook of intelligence (pp. 225-266). New York: Wiley.

Hamilton, M. A., & Hunter, J. E. (1988). PACKAGE.

Hardyck, C. & Petrinovich, L. F. (1977). Left-handedness. Psychological Bulletin, 84, 385-404.

Harris, L. J. (1980). Left-handedness: Early theories, facts, and fancies. In J. Herron (Ed.), Neuropsychology of left-handedness (pp. 3-78). New York: Academic Press.

Harris, L. J. (1985). Teaching the right brain: Historical perspective on a contemporary educational fad. In C. T. Best (Ed.), Hemispheric function and collaboration in the child (pp. 231-174). New York: Academic Press.

Harris, L. J. (1990a). Are spatial abilities poorer in "forced" left-handers? If so, why? Developmental Neuropsychology, 6, 57-70.

Harris, L. J. (1990b). Cultural influences on handedness: Historical and contemporary theory and evidence. In S. Coren (Ed.), Left-handedness: Behavioral implications and anomalies (pp. 195-258). Advances in psychology Vol. 67. Elsevier Science Publishers B.V./North-Holland Book Series.

Harris, L. J. (1991a). Cerebral control of speech in right-handers and left-handers: An analysis of the views of Paul Broca, his contemporaries, and his successors. Brain and Language, 40, 1-50.

Harris, L. J. (1992a). Lefthandedness. In I. Rapin, & S. J. Segalowitz (Eds.), Handbook of neuropsychology. Section 10: Developmental neuropsychology. New York: Elservier. (In Press)

Harris, L. J. (1992b). Handedness in apes and monkeys: Some views from the past. In J. Ward (Ed.), Current behavioral evidence of primate asymmetries. New York: Springer-Verlag. (In Press)

Harris, L. J., & Carlson, D. F. (1988). Hand preference for visually guided reaching in human infants and adults. Behavioral and Brain Sciences, 11, 726-727.

Harris, L. J., & Carlson, D. F. (1992). Hand preference for visually-guided reaching in human infants and adults. In J. Ward (Ed.), Current behavioral evidence of primate asymmetries. New york: Springer-Verlag.

Hatta, T., & Nakatsuka, Z. (1976). Note on hand preference of Japanese people. Perceptual and Motor Skills, 42, 530.

Healey, J. M., Liederman, J., & Geschwind, N. (1986). Handedness is not a unidimensional trait. Cortex, 22, 33-53.

Hécaen, H., Sauguet, J. (1971). Cerebral dominance in left handed subjects. Cortex, 7, 19-48.

Hicks, R, E., & Kinsbourne, M. (1976). Human handedness: A partial cross fostering study. Science, 192, 908-910.

Homzie, M. J., & Lindsay, J. S. (1984). Language and the young stutterer: A new look at old theories and findings. Brain and Language, 22, 232-252.

Hotelling, H. (1933). Analysis of a complex of statistical variables into principal components. Journal of Educational Psychology, 24, 417-441, 498-520.

Hull, C. J. (1936). A study of laterality test items. Journal of Experimental Education, 4, 287-290.

Humphrey, M. E. (1951). Consistency of hand use. British Journal of Educational Psychology, 21, 214-225.

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

Hunter, J. E. (1977). Cluster analysis: Reliability, construct validity, and the multiple indicators approach to measurement. Presented at Workshop on Advanced Statistics given at the U.S. Civil Commission, March.

Hunter, J. E. (1980). Factor analysis. In P. R. Monge, & J. N. Cappella (Eds.), Multivariate technique in human communication research (pp. 229-257). New York: Academic Press.

Hunter, J. E. (1984). Specific error, specific factors, hierarchical measurement models, and second order factor analysis. Unpublished manuscript, Department of Psychology, Michigan State University.

Hunter, J. E. (1985). Factor analysis outline. Unpublished manuscript, Department of Psychology, Michigan State University.

Hunter, J. E. (1988). A comparison of exploratory and confirmatory factor analysis. Presented at Workshop on Structural Analysis, January, Madras, India.

Hunter, J. E. (1991). BICPACK

Inglis, J., & Lawson, J. S. (1981). Sex differences in the effects of unilateral brain damage on intelligence. Science, 212, 693-695.

Johnston, J., Galin, D., & Heron, J. (1979). Choice of handedness measures in studies of hemispheric specialization. International Journal of Neuroscience, 9, 71-80.

Jöreskog, K. G. (1979). Basic ideas of factor and component analysis. In K. G. Jöreskog, & D. Sörbom (Eds.), Advances in factor analysis and structural equation models (pp.5-43). Cambridge, MA: Abt Books.

Kaiser, H. F. (1958). The varimax criterion for analytic rotation in factor analysis. Psychometrika, 23, 187-200.

Kimura, D. (1977). Acquisition of a motor skill after left hemisphere damage. Brain, 100, 527-542.

Kimura, D. (1982). Left-hemisphere control of oral and brachial movements and their relation to communication. Philosophical Transaction of the Royal Society of London, 298, 135-149.

Kimura, D. (1983). Sex differences in cerebral organization for speech and praxis function. Canadian Journal of Psychology, 37, 19-35.

Kimura, d., & Archibald, Y. (1974). Motor functions of the left hemisphere. Brain, 97, 337-350.

Kertesz, A., & Geschwind, N. (1971). Patterns of pyramidal decussation and their relationship to handedness. Archives of Neurology, 24, 326-332.

Komai, T., & Fukuoka, G. (1934). A study of the frequency of left-handedness and left-footedness among Japanese school children. Human Biology, 6, 33-42.

Kuypers, H. G. J. M. (1982). Anatomy of descending pathways to the spinal cord. New York: Elsevier Biomedical Press.

Lake, D. A., & Bryden, M. P. (1976). Handedness and sex differences in hemispheric asymmetry. Brain and Language, 3, 266-282.

Lansdell, H. (1961). The effect of neurosurgery on a test of proverbs. American Psychologist, 16, 448. Abstract.

Lansdell, H. (1968). The use of factor scores from the Wechsler-Bellevue Scale of Intelligence in assessing patients with temporal lobe removals. Cortex, 4, 257-268.

Lansdell, H. (1973). Effect of neurosurgery on the ability to identify popular word associations. Journal of Abnormal Psychology, 81, 255-258.

Lansky, L. M., Feinstein, H., & Peterson, J. M. (1988). Demography of handedness in two samples of randomly selected adults (N=2083). Neuropsychologia, 26, 465-477.

Lawrence, D. g., & Kuypers, H. G. J. M. (1968). The functional organization of the motor system in the monkey: I. The effects of bilateral pyramidal lesions. Brain, 91, 1-14.

Leiber, L., & Axelrod, S. (1981). Intra-familial learning is only a minor factor in manifest handedness. Neuropsychologia, 19, 273-288.

Levander, M., & Schalling, D. (1988). Hand preference in a population of Swedish college students. Cortex, 24, 149-156.

Levy, J. (1976). A review of evidence for a genetic component in the determination of handedness. Behavior Genetics, 6, 429-453.

Levy, J., & Nagylaki, T. (1972). A model for the genetics of handedness. Genetics, 72, 117-128.

Levy, J., & Gur, R. C. (1980). Individual differences in psychoneurological organization. In J. Herron (Ed.), Neuropsychology of left-handedness (pp. 199-210). New York: Academic Press.

Lewis, R. S., & Harris, L. J. (1990). Handedness, sex, and spatial ability. In S. Coren (Ed.), Left-handedness: Behavioral implications and anomalies (pp. 195-258). Advances in psychology Vol. 67. Elsevier Science Publishers B.V./North-Holland Book Series.

Longstreth, L. E. (1980). Human handedness: More evidence for genetic involvement. Journal of Genetic Psychology, 137, 275-283.

Maccoby, E. E., & Jacklin, C. N. (1974). The psychology of sex differences. Standford, Calif.: Standford University Press.

MacNeilage, P. F., Studdert-Kennedy, M. G., & Lindblom, B. (1987). Primate handedness reconsidered. Behavioral and Brain Sciences, 10, 247-303.

MacNeilage, P. F., Studdert-Kennedy, M. G., & Lindblom, B. (1988). Primate handedness: A foot in the door. Behavioral and Brain Sciences, 11, 737-744.

Marrion, L. V. (1986). Writing-hand differences in Kwakiutls and Caucasians. Perceptual and Motor Skills, 62, 760-762.

McFarland, K., & Anderson, J. (1980). Factor stability of the Edinburgh Handedness Inventory as a function of test-retest performance, age, and sex. British Journal of Psychology, 71, 135-142.

McGee, M. G., & Cozad, T. (1980). Population genetic analysis of human hand preference: Evidence for generation differences, familial resemblance, and maternal effects. Behavior Genetics, 10, 263-276.

McGlone, J. (1980). Sex differences in human brain asymmetry: A critical survey. The Behavioral and Brain Sciences, 3, 215-263.

McGlone, J., & Kertesz, A. (1973). A sex differences in cerebral processing of visuospatial tasks. Cortex, 9, 313-320.

McGuire, W. J., & McGuire, C. V. (1980). Salience of handedness in the spontaneous self-concept. Perceptual and Motor Skills, 50, 3-7.

McKeever, W. F., & Van Deventer, A. D. (1977). Familial sinistrality and degree of left-handedness. British Journal of Psychology, 68, 469-471.

McManus, I. C. (1984). Genetics of handedness in relation to language disorder. Advances in Neurology, 42, 125-138.

McManus, I. C. (1985). Right- and left-hand skill: Failure of the right shift model. British Journal of Psychology, 76, 1-16.

Merrell, D. J. (1957). Dominance of eye and hand. Human Biology, 29, 314-328.

Michel, G. F., Ovrut, M. R., & Harkins, D. A. (1986). Hand-use preference for reaching and object manipulation in 6- through 13-month-old infants. Genetic, Social, and General Psychology Monographs, 111, 409-427.

Money, J. (1972). Studies on the functioning of sighting dominance. Quarterly Journal of Experimental Psychology, 24, 454-464.

Morgan, M. J. (1977). Embryology and inheritance of asymmetry. In S. Harnad, R. W. Doty, L. Goldstein, J. Jaynes, & G. Krauthamer (Eds.), Lateralization in the nervous system (pp. 173-194). New York: Academic Press.

Morgan, M. J. & Corballis, M. C. (1978). On the biological basis of human laterality. II. The mechanism of inheritance. The Behavioral and Brain Sciences, 1, 207-277.

Myers, R. H. (1990). Classical and modern regression with applications. Boston, Mass: PWS-KENT Publishing Company.

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

Orton, S. T. (1937). Specific reading disability - strephosymbolia. Journal of the American Medical Association, 90, 1095-1099.

Payne, M. A. (1981). Incidence of left-handedness for writing: A study of Nigerian primary school children. Journal of Cross Cultural Psychology, 12, 233-239.

Payne, M. A. (1987). Impact of cultural pressures on self-reports of actual and approved hand use. Neuropsychologia, 25, 247-258.

Peters, M. (1986). Incidence of left-handed writers and the inverted writing position in a sample of 2,194 German elementary school children. Neuropsychologia, 24, 429-433.

Peters, M. (1988). Footedness: Asymmetries in foot preference and skill and neuropsychological assessment of foot movement. Psychological Bulletin, 103, 179-192.

Peters, M. (1990a). Phenotype in normal left-handers: An understanding of phenotype is the basis for understanding mechanism and inheritance of handedness. In S. Coren (Ed.), Left-handedness: Behavioral implications and anomalies (pp. 167-192). Advances in psychology Vol. 67. Elsevier Science Publishers B.V./North-Holland Book Series.

Peters, M. (1992). How sensitive are handedness prevalence figures to differences in questionnaire classification procedures? Brain and Cognition, 18, 208-215.

Peters, M., & Durding, B. M. (1978). Handedness measured by finger tapping: A continuous variable. Canadian Journal of Psychology, 32, 257-261.

Peters, M., & Durding, B. M. (1979a). Footedness of left- and right-handers. American Journal of Psychology, 92, 133-142.

Peters, M., & Durding, B. M. (1979b). Left-handers and right-handers compared on a motor task. Journal of Motor Behaviors, 11, 103-111.

Peters, M., & Servos, P. (1989). Performance of subgroups of left-handers and right-handers. Canadian Journal of Psychology, 43, 341-358.

Peterson, J. M. (1979). Left-handedness: Differences between student artists and scientists. Perceptual and Motor Skills, 48, 961-962.

Plato, C. C., Fox, K. M., & Garruto, R. M. (1984). Measures of lateral functional dominance: Hand dominance. Human Biology, 56, 259-275.

Ponton, C. W. (1987). Enhanced articulatory speed in ambidexters. Neuropsychologia, 25, 305-311.

Porac, C., & Coren, S. (1976). The dominant eye. Psychological Bulletin, 83, 880-897.

Porac, C., & Coren, S. (1978). Relationship between lateral preference behaviors in humans. The Behavioral and Brain Sciences, 2, 311-312.

Porac, C., & Coren, S. (1979). A test of the validity of offsprings' report of parental handedness. Perceptual and Motor Skills, 49, 227-231.

Porac, C., & Coren, S. (1981). Laterality preference and human behavior. New York: Springer-Verlag.

Porac, C., Coren, S., & Duncan, P. (1980). Life-span age trends in laterality. Journal of Gerontology, 35, 715-721.

Porac, C., Coren, S., Searleman, A. (1986). Environmental factors in hand preference formation: Evidence from attempts to switch the preferred hand. Behavior Genetics, 16, 251-261.

Porac, C., Rees, L., & Buller, T. (1990). Switching hands: A place for left hand use in a right hand world. In S. Coren (Ed.), Left-handedness: Behavioral implications and anomalies (pp. 259-290). Advances in psychology Vol. 67. Elsevier Science Publishers B.V./North-Holland Book Series.

Porac, C., Coren, S., Steiger, J. H., & Duncan, P. (1980). Human laterality: A multidimensional approach. Canadian Journal of Psychology, 34, 91-96.

Previc, F. H. (1991). A general theory concerning the prenatal origins of cerebral lateralization in humans. Psychological Review, 98, 299-334.

Provins, K. A., & Cunliffe, P. (1972). The reliability of some motor performance tests of handedness. Neuropsychologia, 10, 199-206.

Provins, K. A., Milner, A. D., & Kerr, P. (1982). Asymmetry of manual preference and performance. Perceptual and Motor Skills, 54, 179-194.

Raczkowski, D., Kalat, J. W., & Nebes, R. (1974). Reliability and validity of some handedness questionnaire items. Neuropsychologia, 12, 43-47.

Ramaley, F (1913). Inheritance of left-handedness. American Naturalist, 47, 730-738.

Rasmussen, T., & Milner, B. (1977). The role of early left-brain injury in determining lateralization of cerebral speech functions. Annals of the New York Academy of Sciences, 299, 355-369.

Richardson, J. T. E. (1978). A factor analysis of self-reported handedness. Neuropsychologia, 16, 747-748.

Rife, D. C. (1940). Handedness with special reference to twins. Genetics, 25, 178-186.

Salmaso, D., & Longoni, A. M. (1983). Hand preference in an Italian sample. Perceptual and Motor Skills, 57, 1039-1042.

Salmaso, D., & Longoni, A. M. (1985). Problems in the assessment of hand preference. Cortex, 21, 533-549.

Satz, P., Achenbach, K., & Fennell, E. (1967). Correlations between assessed manual laterality and predicted speech laterality in a normal population. Neuropsychologia, 5, 295-310.

Searleman, A. (1980). Subject variables and cerebral organization. Cortex, 16, 239-254.

Searleman, A., & Fugagli, A. K. (1987). Suspected autoimmune disorders and left-handedness: Evidence from individuals with diabetes, Crohn's disease, and ulcerative colitis. Neuropsychologia, 25, 367-374.

Searleman, A., Tweedy, J., & Springer, S. (1979). Interrelationships among subject variables believed to predict cerebral organization. Brain and Language, 7, 267-276.

Segalowitz, S. J., & Bryden, M. P. (1983). Individual differences in hemispheric representation of language. In S. J. Segalowitz (Ed.), Language functions and brain organization (pp. 341-372). New York: Academic Press.

Selzer, C. A. (1933). Lateral dominance and visual fusion. Harvard Monographs in Education, No. 12: Studies in educational psychology and educational measurement. Cambridge, Mass.: Harvard University Press.

Seyal, M., Sato, S., White, B. G., & Porter, R.J. (1981). Visual evoked potentials and eye dominance. Electroencephalography and Clinical Neurophysiology, 52, 424-428.

Shettel-Neuber, J., & O'Reilly, J. (1983). Handedness and career choice: Another look at supposed left/right differences. Perceptual and Motor Skills, 57, 391-397.

Shimizu, A., & Endo, M. (1983). Handedness and familial sinistrality in a Japanese student population. Cortex, 19, 265-273.

Snyder, P. J., & Harris, L. J. (1992). Consistent and inconsistent left-handedness in college students: Incidence and relation to sex, familial sinistrality, and spatial skill. (Submitted)

Spearman, C. (1927). The abilities of man: Their nature and measurement. New York: Macmillan.

Spiegler, B. J., & Yeni-Komshian, G. H. (1983). Incidence of left-handed writing in a college population with reference to family patterns of hand preference. Neuropsychologia, 21, 651-659.

Steenhuis, R. E., & Bryden, M. P. (1987). Handedness: A matter of direction and degree. Canadian Psychology, 28, N.586.

Steenhuis, R. E., & Bryden, M. P. (1989). Different dimensions of hand preference that relate to skilled and unskilled activities. Cortex, 25, 289-304.

Steenhuis, R. E., Bryden, M. P., Schwartz, M., & Lawson, S. (1990). Reliability of hand preference items and factors. Journal of Clinical and Experimental Neuropsychology, 12, 921-930.

Stevens, G., & Featherman, D. L. (1980). A revised socioeconomic index of occupational status. Social Science Research, 10, 364-395.

Tan, L. E. (1983). Handedness in two generations. Perceptual and Motor Skills, 56, 867-874.

Tanner, J. M. (1978). Foetus into man: Physical growth from conception to maturity. Cambridge, Mass.: Harvard University Press.

Tapley, S. M., & Bryden, M. P. (1985). A group test for the assessment of performance between the hands. Neuropsychologia, 23, 215-221.

Teng, E. L., Lee, P., Yang, K., & Chang, P. C. (1976). Handedness in a Chinese population: Biological, social, and pathological factors. Science, 193, 1148-1150.

Teng, E. L., Lee, P., Yang, K., & Chang, P. C. (1979). Lateral preference for hand, foot, and eye and their lack of association with scholastic achievement in 4143 Chinese. Neuropsychologia, 17, 41-48.

Thompson, E. G., & Harris, L. J. (1978). Left-handers' sensitivity to hand usage: Theoretical note on saliency in the self-report. Perceptual and Motor Skills, 47, 833-834.

Thompson, A. L., & Marsh, J. F. (1976). Probability sampling of manual asymmetry. Neuropsychologia, 14, 217-223.

Thurstone, L. L. (1938). Primary mental abilities. Chicago: University of Chicago Press.

Tupper, D. E. (1983). The pattern of lateral preference and motor dominance in children ages 3 to 8. Paper presented at the 11th annual meeting of the International Neuropsychological Society, Mexico City, February.

Verhaegen, P., & Ntumba, A. (1964). Note on the frequency of left-handedness in African children. Journal of Educational Psychology, 55, 89-90.

Wada, J., Clarke, R., & Hamm, A. (1975). Cerebral hemispheric asymmetry in humans: Cortical speech zones in 100 adult and 100 infant brains. Archives of Neurology, 32, 239-246.

Walls, G. L. (1951). A theory of ocular dominance. A.M.A. Archives of Ophthalmology, 45, 387-412.

Warren, J. M., Abplanalp, J. M., & Warren, H. B. (1967). The development of handedness in cats and rhesus monkeys. In H. W. Stevenson, E. H. Hess, & H. L. Rheingold (Eds.), Early behavior: Comparative and developmental approaches (pp. 73-101). New York: Wiley.

Webster, W. G., & Poulos, M. (1987). Handedness distributions among adults who stutter. Cortex, 23, 705-708.

White, K., & Ashton, R. (1976). Handedness assessment inventory. Neuropsychologia, 14, 261-264.

Williams, S. (1986). Factor analysis of the Edinburgh Handedness Inventory. Cortex, 22, 325-326.