PREFERENCE AND PROFICIENCY DEFINITIONS OF HANDEDNESS: A COMPARATIVE STUDY

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CURRICULUM STUDIORUM

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INTRODUCTION

Laterality, in general, and handedness, specifically, are phenomena which have enjoyed considerable attention from both past and present-day researchers. Reading of articles spanning the last fifty years, however, intimated to this writer that little progress has been made in their investigation. Repeated attempts to relate handedness to such phenomena as visual and auditory perception, language development, stuttering and motor abilities have failed to uncover any number of reliable findings.

It is this investigator's contention that the lack of consistent progress in this field has stemmed largely from insufficient attention and effort given both to the clarification and precise definition of handedness as a phenomenon, and to the development of adequate measurement tools. Many operational definitions have been volunteered in an attempt to describe and account for the complexity of handedness. A majority of researchers, however, seem to have presumed, without supporting rationale, that their definitions adequately described the total phenomenon.

These considerations led to the planning of this research. This study was a preliminary effort aimed primarily at clarifying the concept of handedness and investigating the interrelationships between the most widely supported operational definitions of this phenomenon; namely, as the degree of consistency in hand preference and as the levels of relative and preferred hand skill.

The following paragraph presents an overview of the formal divisions of this research paper.

Chapter I contains a review of pertinent literature underscoring the theoretical and methodological inadequacies in handedness research and leading to a statement of the general research hypotheses. A description of the sample and procedures for testing the specific hypotheses are included in Chapter II. Chapter III presents and discusses the results of the experiment. A summary of findings and conclusions terminates the formal write-up of this research.

CHAPTER I

REVIEW OF THE LITERATURE

A review of the range of definitions of handedness provided in the literature will highlight the complexity of the construct. The need to provide a theoretical basis for a definition of handedness will be shown and an attempt to develop such a rationale will be made. The most prevalent definitions of handedness, namely, the preference and proficiency definitions, will be evaluated in the light of the elaborated rationale. In order to investigate the statistical relationships between these two types of definitions, their methods of assessment will be reviewed and appraised. Previous attempts to relate the preference and proficiency measures of handedness will then be reviewed, underscoring the need for further and more refined study of their relationships.

1. Definitions of Handedness: A Review.

Investigators have demonstrated little agreement in their definitions of the handedness construct. Beck, nearly forty years ago, reviewing the wide variety of test measures of handedness, concluded that the "word 'handedness' has been used in many instances as a blanket term, standing for almost any kind of morphological or functional difference between the two hands,"[1] i.e., the relative length of forearms, relative density of fingertip whorls, relative speed of nervous conduction, nervous excitability, the degree of slant in hand writing, relative skill, strength, use, preference, and others.

While most measures of constitutional variability are used as specific measures of handedness only infrequently today, preference and proficiency measures of handedness have gained wider use and support. For Burt,[2] handedness was the preferred hand in novel tasks. Martin defined handedness as "the exhibition of a consistent laterality preference [...]."[3] Proficiency definitions of handedness were given by Hildreth, "handedness is a matter of degree determined by the difference in the skill with which both hands are used";[4] by Way,[5] handedness is the superior hand proficiency on a

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1 L. F. Beck, "Manual Skills and the Measurement of Handedness," in Journal of Psychology, Vol. 2, 1936, p. 259.

2 C. Burt, The Backward Child, London, University of London Press, 5th edition, 1961, p. 271.

3 K. L. Martin, "Handedness: A Review of the Literature on the History, Development and Research of Laterality Preference," in Journal of Educational Research, Vol. 45, 1952, p. 527.

4 G. Hildreth, "The Development and Training of Hand Dominance: I. Characteristics of Handedness," in Journal of Genetic Psychology, Vol. 75, 1949, p. 201.

5 E. E. Way, "Relationship of Lateral Dominance to Scores of Motor Ability and Selected Skill Tests," in Research Quarterly of the American Association of Health, Physical Education and Recreation, Vol. 29, 1958, p. 360-369.

series of motor skill tasks, and by Barnsley and Rabinovitch, handedness is the "degree of differentiation between preferred and non-preferred hand performance."[6]

Some definitions of handedness include both the notions of preference and better performance. Brain offered one example: "Handedness, therefore, is nothing absolute; it is a question of degree, a preference based on the difference in the skill with which the two hands are used."[7] Harris offered another regarding the more general pattern of sidedness: "Lateral dominance means the preferred use and better performance of one side of the body as compared with the other side."[8] These definitions seem to imply that preferential use and superior proficiency are closely related if not synonymous phenomena.

Several authors have developed classifications of the various operational definitions of handedness. Barnsley,[9] in 1970, reviewing Benton, Meyers and Polder's[10] classification

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6 R. H. Barnsley and M. S. Rabinovitch, "Handedness and 'Automatization' Cognitive Style," in Canadian Journal of Psychology, Vol. 27, No. 1, 1973, p. 7.

7 W. R. Brain, "Speech and Handedness," in Lancet, Vol. 2, 1945, p. 837.

8 A. J. Harris, Harris Tests of Lateral Dominance, Manual of Directions for Administration and Interpretation, New York, Psychological Corp., 1958 (3rd ed.), p. 3.

9 R. H. Barnsley, Handedness and Related Behavior, unpublished doctoral dissertation, McGill University, 1971, p. 2.

10 A. L. Benton, R. Meyers, and G. J. Polder, "Some Aspects of Handedness," in Psychiatria et Neurologia, Basel, Vol. 144, 1962, p. 321-337.

of handedness, suggested that basically there are three ways of operationally describing handedness. The first is a typological classification: individuals are considered right-handed or left-handed or perhaps as ambidextrous on the strength of a verbal report. A second definition views handedness in terms of preferential hand usage. It includes degrees of right- and left-handedness and makes provision for the measurement of the phenomenon on an interval scale. A third view considers handedness in terms of the actual performance differences between the two hands. Handedness is the differential hand proficiency as measured by assessing the skill of both the preferred and non-preferred hands on one or more motor tests. A fourth definition, supported by the results of Barnsley's[11] study, views handedness as the level of preferred hand proficiency.

The above classification points to differential treatment of the handedness factor. Some investigators recognize only two groups: right- and left-handers. Handedness is seen as a dichotomous variable. Some definitions allow for three varieties of handedness: right-, left-, and mixed-handedness, all of which are genetically determined.[12] A third view holds that handedness is basically a continuous

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11 Barnsley, op. cit., p. 69-74.

12 M. Annett, "A Model of the Inheritance of Handedness and Cerebral Dominance," in Nature, Vol. 204, 1964, p. 59-60.

variate whether of lateral preference as suggested by Woo and Pearson[13] and Annett,[14] or of manual proficiency as intimated by Brain,[15] Barnsley and Rabinovitch,[16] and Barnsley.[17] This third conceptualization of handedness as a question of degree seems to enjoy the greatest support in the current literature.

Most of the definitions presented above are operational in nature. Their variety bespeaks of the conceptual diversity associated with the handedness construct. Is handedness a unitary concept? Does it label a monofactorial phenomenon or does it stand for several if not many different variables, each of which may contribute differentially to the total phenomenon? Many studies proceed to assess handedness either via questionnaire or proficiency measures or a combination of both measures without speaking to the nature of the construct they are attempting to measure. The need for both a more adequate conceptualization and operational definition

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13 T. L. Woo and K. Pearson, "Dextrality and Sinistrality of Hand and Eye," in Biometrika, Vol. 19, 1927, p. 199.

14 M. Annett, "A Classification of Hand Preference by Association Analysis," in British Journal of Psychology, Vol. 61, No. 3, 1970a, p. 303-321.

15 Brain, op. cit., p. 837-841.

16 R. H. Barnsley and M. S. Rabinovitch, "Handedness: Proficiency versus Stated Preference," in Perceptual and Motor Skills, Vol. 30, 1970, p. 343-362.

17 Barnsley, op. cit., 145 p.

of handedness seems undeniable if some standardization in measurement tools and consistency in results is to be achieved in this area of research.

In summary, two definitions seem to have gained greater consensual validity: the first defines handedness in terms of consistent preference for one hand; the second as the degree of differential or preferred hand skill. It was noted that many investigators have failed to provide an adequate conceptual framework for their operational definitions. They have for the most part assumed that to define handedness as preference or as degree of skill required little or no justification. That a preference or performance or any other definition of handedness for that matter adequately represented the phenomenon of handedness seems to have been frequently taken for granted.

In the next section, an attempt will be made to provide a rationale for defining handedness and critically appraise both the preference and proficiency definitions in the light of the elaborated rationale.

2. Rationale for a Definition of Handedness.

Most researchers seem to agree that handedness represents the development of an asymmetry in function. One hand tends to become preferred, dominant, more skillful than the other. The development of functional asymmetries in the human organism, however, is by no means restricted to the handedness phenomenon. Asymmetries in auditory and visual perception,[18] hemispheric control of motor functions,[19] speech lateralization,[20] and others have been reported and documented.

Many authors have defined and studied handedness within the framework of other lateral asymmetries in man, notably that of the foot and the eye. Hécaen and Ajuriaguerra[21] viewed the notion of manual laterality as too restrictive since it did not take into account the laterality of the eye and lower limbs. The weight of the evidence, however, intimates very little relation between hand and eye dominance;[22,23] and a generally low degree of relation between hand and foot

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18 E. B. Zurif and M. P. Bryden, "Familial Handedness and Left-Right Differences in Auditory and Visual Perception," in Neuropsychologia, Vol. 7, 1969, p. 179-187.

19 J. Semmes, "Hemispheric Specialization: A Possible Clue to Mechanism," in Neuropsychologia, Vol. 6, 1966, p. 11-26.

20 J. Wada and T. R. Rasmussen, "Intracarotid Injection of Sodium Amytal for the Lateralization of Cerebral Speech Dominance," in Journal of Neurosurgery, Vol. 17, 1960, p. 266-282.

21 H. Hécaen and J. de Ajuriaguerra, Les gauchers: prévalence manuelle et dominance cérébrale, Paris, Presses Univ. de France, 1963, 161 p.

22 G. Groden, "Lateral Preferences in Normal Children," in Perceptual and Motor Skills, Vol. 28, No. 1, 1969, p. 213-214.

23 D. M. Gronwall and H. Sampson, "Ocular Dominance: A Test of Two Hypotheses," in British Journal of Psychology, Vol. 62, No. 2, 1971, p. 175-185.

asymmetries.[24,25] Dayhaw,[26] having reviewed the literature comparing the various lateral asymmetries in man, concluded that human laterality is not unitary in character.

On the strength of these findings, this writer argues that handedness is a phenomenon distinct from eyedness and footedness and need be defined and investigated as such.

A. The Development of Functional Asymmetry in Handedness

Many theories have been proposed to explain the mechanisms which underlie the development of functional specialization in handedness, but none have sufficient evidence to back them up.[27] Most factors proposed to account for handedness have come under the umbrellas of hereditary or learning influences. After an early period of polarization of opinion, most investigators today tend toward a multi-causal explanation of hand laterality.[28,29] Hécaen and

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24 L. W. Irwin, "A Study of the Relationship of Dominance to the Performance of Physical Education Activities," in American Association for Health, Physical Education and Recreation Research Quarterly, Vol. 9, No. 2, 1938, p. 98-119.

25 Way, op. cit., p. 363-365.

26 L.-T. Dayhaw, "De la préférence latérale chez l'homme," in Revue de l'Université d'Ottawa, Vol. 21, 1951, p. 89.

27 M. Gardner, The Ambidextrous Universe, New York, Basic Books, 1964, p. 77.

28 A. R. Kaplan, "On the Problem of Lateral Neuromuscular Dominance," in Psychiatria et Neurologia, Basel, Vol. 149, 1965, p. 371-372.

29 K. A. Provins, "Motor Skills, Handedness and Behavior," in Australian Journal of Psychology, Vol. 19, No. 2, 1967, p. 146.

Ajuriaguerra concluded: "Lateralization is a potentiality in the human infant influenced by hereditary, environmental and social pressures."[30] Heredity, therefore, seems to define the limits of capacity for development within which environmental factors and social pressures will work.

Granted that many factors affect the phenotypic development of hand laterality, the central question of purpose remains. Does this tendency to functional asymmetry benefit the organism?

Hildreth[31] linked the advent of human handedness to increasing differentiation and refinement in motor skills. She suggested that, as man developed into a tool-user, adaptive advantages resulted from increased unilateral specialization. Handedness, and the greater unimanual dexterity usually associated with it may have proved to possess a high survival value both in the use of tools and weapons. "The complementary functioning of the two hands with division of labor between them makes for economy and efficiency in performance."[32]

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30 Hécaen and Ajuriaguerra, op. cit., p. 148.

31 Hildreth, op. cit., p. 205-206.

32 Ibid., p. 199.

Corballis and Beale,[33] in a recent theoretical article on the relation of symmetry and behavior, suggested that, with the evolution of conceptual functions not tied down to the immediate environment, symmetry of function may frequently have proved a disadvantage. Their main thesis that bilaterally symmetrical organisms cannot discriminate left from right was borrowed from the work of Ernst Mach.[34] It led the authors to suggest that in order to solve problems in mirror-image discrimination, organisms adopt asymmetrical response biases. Hand preference, they argued, is one example of a consistent response bias where symmetry of function may have proved a hindrance. The level of "efficiency" of the organism's manipulative interactions with its environment seems to be enhanced by the adoption of a consistent response bias. The work of these researchers supported the efficiency rationale for the development of asymmetry in handedness.

Palmer[35] attempted to establish a developmentally oriented conceptual framework for handedness. He reviewed

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33 M. C. Corballis and I. L. Beale, "Bilateral Symmetry and Behavior," in Psychological Review, Vol. 77, No. 5, 1970, p. 451-464.

34 E. Mach, Popular Scientific Lectures, Chicago, Open Court Publishing House, 1894, quoted in Corballis and Beale, *op. cit.*, p. 451.

35 R. D. Palmer, "Development of a Differentiated Handedness," in Psychological Bulletin, Vol. 62, No. 4, 1964, p. 256-272.

articles by Gesell and Ames[36] and others who stressed the role of maturational components in the development of manifestations of one-sidedness. Palmer rejected what he termed a "narrow view" which fails to recognize that handedness is rooted in more general aspects of motor development.[37] In this framework, the achievement of a significant degree of one-sidedness is indicative of a similarly high level of motor development.

> If [...] one-sidedness is viewed as a "differentiation from a whole," then the degree of lateralization of manual functions observed in an individual might be utilized as one index of his motor development. In this view, a normally developing individual possessing a strongly lateralized pattern of hand skill must probably be viewed as more differentiated motorically than a more ambilateral individual, and as having achieved a "developmentally later" or "developmentally more advanced" level of motor functioning.[38]

In this framework, increases in the degree of lateralization of manual functions are closely associated with increments in proficiency on a variety of measures tapping significant dimensions of motor development. Asymmetry in handedness, thus, procures adaptive advantages in terms of the betterment of motoric skills.

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36 A. Gesell and L. B. Ames, "The Development of Handedness," in Journal of Genetic Psychology, Vol. 70, 1947, p. 155-175.

37 Palmer, op. cit., p. 257.

38 --------, "Dimensions of Differentiation in Handedness," unpublished paper presented to the Eastern Psychological Association, Boston, 1967, p. 2.

The studies cited above suggested essentially that the development of functional asymmetry in handedness conferred adaptive advantages upon the human organism. Crinella, Beck and Robinson[39] in 1971 took issue with this position. Comparing a sample of behaviorally impaired brain-damaged children with another of children above average in academic standing, they found low correlations between lateral agreement (LA) and strength of lateral preference (SLP) and seventy neuropsychological test measures. Chronological age was shown to be a better predictor of neuropsychological development. This writer, while acknowledging the value of the results, expresses some reservations regarding the interpretation given them. First, the LA and SLP measures of lateralization appeared to be **assessing a somewhat complex domain** they included measures of both eye and foot preference as well as hand preference. The authors provided substantive evidence which failed to support the Doman-Delacato[40] position stressing the interdependence of lateral preferences with general neuropsychological differentiation and integration at

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39 F. M. Crinella, F. W. Beck, and J. W. Robinson, "Unilateral Dominance Is Not Related to Neuropsychological Integrity," in Child Development, Vol. 42, 1971, p. 2033-2054.

40 R. J. Doman, E. B. Spitz, E. Zucman, C. H. Delacato, and G. Doman, "Children with Severe Brain Injuries: Neurological Organization in Terms of Mobility," in Journal of the American Medical Association, Vol. 174, 1960, p. 257-262.

the higher levels of the CNS. However, the possibility that lateral preference variables may confer adaptive advantages in terms of the more simple dimension of motor functioning, may not be summarily rejected on the basis of these results. More adequate measures of the motor proficiency dimension would be essential in a test of the latter hypothesis.

B. Implications for an Operational Definition of Handedness

The literature has provided some theoretical support, albeit not consistently, for the view that handedness provides one example of an asymmetrical mode of functioning which derives its raison d'être from the adaptive advantages it confers to the human organism in terms of enhanced motor proficiency. Does this hypothesized link between the adoption of a consistent response bias in handedness and enhanced manipulative efficiency contribute to, or fail to support, operational definitions of handedness as preference or proficiency?

A relationship between the adoption of a response bias and the development of consistency in hand preference seems fairly direct. It supports an operational definition of handedness in terms of preference. The enhanced manipulative efficiency dimension may be interpreted to signify increased levels of hand skill and supports an operational definition of handedness in terms of proficiency. A relation between the consistency in hand preference and hand skill operational definitions of handedness is thus postulated on the basis of the theoretical link between the development of asymmetrical functioning in handedness and the resulting improvement in motoric efficiency of the organism. This latter dimension may be interpreted in two ways: as reflecting the development of greater levels of skill in one hand or as pointing to increases in the relative levels of hand skill. These two interpretations are reflected in the two types of operational definitions of handedness involving proficiency measures: the first stressing the level of preferred hand skill; the second emphasizing increases in skill differences between the hands.

Support for these two operational definitions of handedness raises the question of equivalence. To what extent are these definitions interchangeable? Palmer[41] failed to find support for the notion that a unitary process or dimension of specialization underlied handedness. Benton, Meyers and Polder,[42] at the conclusion of study investigating the relation of preference and proficiency measures of handedness, suggested that there may be different components making

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41 Palmer, <u>op. cit</u>., 1964, p. 269.

42 Benton <u>et al</u>., <u>op. cit</u>., p. 334-335.

separate contributions to the handedness phenomenon. Hildreth[43] maintained that a central problem in studying handedness was to investigate the relationship of relative skill to hand preference. Implicit seems the suggestion that these are not equivalent descriptions of handedness. It is fairly evident that some relation should exist between them if the link between response bias and enhanced motor efficiency possesses any validity.

Some studies which have investigated the relation between these two definitions of handedness will be discussed in a later section. In order to permit a more adequate appraisal of these, assessment procedures for the preference and proficiency definitions of handedness will be presented and reviewed critically in the coming pages.

3. The Assessment of Handedness.

Research in the area of handedness is often very weak at its base, in the measurement of the concept. Measures of preference and proficiency definitions of handedness will be discussed in that order.

A. The Assessment of Hand Preference

A wide variety of techniques have been employed, not all of them adequately representing the complexity of

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43 Hildreth, op. cit., p. 205.

handedness as a continuous variable. They range from procedures requesting a verbal statement about the subject's handedness (i.e., Are you right-handed or left-handed?) from the individual himself or from his parents, to questionnaires using either strictly unimanual or both unimanual and bimanual tasks, to procedures relying on direct observation of hand usage. Questionnaires of preferential handedness have been the most widely used technique.

There exist nearly as many varieties of questionnaires of handedness as there are researchers who have employed this procedure. Sets of items differing in their range and number of activities have been proposed according to the purpose and scope of the investigation.

Questionnaires of hand preference today are concerned most exclusively with familiar unimanual tasks[44,45] although earlier investigators also included bimanual activities.[46,47] Barnsley[48] underscored two of the main criticisms of bimanual

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44 M. E. Humphrey, "Consistency of Hand Usage: A Preliminary Enquiry," in British Journal of Educational Psychology, Vol. 21, 1951, p. 214-225.

45 H. F. Crovitz and K. Zener, "A Group Test of Assessing Hand- and Eye-Dominance," in American Journal of Psychology, Vol. 75, 1962, p. 271-276.

46 H. L. Koch, "A Study of the Nature, Measurement, and Determination of Hand Preference," in Genetic Psychology Monographs, Vol. 13, 1933, p. 117-221.

47 C. E. Lauterbach, "The Measurement of Handedness," in Journal of Genetic Psychology, Vol. 43, 1933, p. 207-212.

48 Barnsley, op. cit., p. 16.

activities: their unreliability of measurement and their seeming lack of significance. In a recent study, Bruml agreed with Barnsley and maintained that it is essential to distinguish between unimanual and bimanual activities since "bimanual measures show a much slower rise toward consistent behavior than unimanual measures do."[49] This writer surmises that bimanual activities probably contribute in an as yet unclear way to the global phenomenon of handedness. However, an attempt to elucidate their potential significance is beyond the scope of this review.

Questionnaires yield various types of measures of hand preference. Some simply attempt to ascribe individuals to one of two discrete categories, that of right- or left-handedness. Others yield a quantitative index of one's degree of lateral preference. The formula (R-L)/(R+L) yields a ratio of right- and left-hand preferences and is basically that employed by Durost,[50] Burt,[51] and Oldfield.[52] It possesses

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49 H. Bruml, "Age Changes in Preference and Skill Measures of Handedness," in Perceptual and Motor Skills, Vol. 34, No. 1, 1972, p. 12.

50 W. N. Durost, "The Development of a Battery of Objective Group Tests of Manual Laterality with the Results of their Application to 1300 Children," in Genetic Psychology Monographs, Vol. 16, 1934, p. 279.

51 C. Burt, The Backward Child, London, University of London Press, 1961 (5th ed.), p. 272.

52 R. C. Oldfield, "The Assessment and Analysis of Handedness: The Edinburgh Inventory," in Neuropsychologia, Vol. 9, 1971, p. 97-113.

the advantage of being easily interpretable: the size of the indices is limited from -1.00 to +1.00 where a minus score always represents an excess of left-hand preferences and a positive score greater preference for the right hand.

The questionnaires are of uneven value. Some included large pools of items, both unimanual and bimanual, tapping learned and unlearned handedness. These pools probably included most potentially relevant items; they failed, however, to discriminate those items which added nothing or actually detracted from the total score from those which contributed to it (i.e., Koch[53] in 1933 used a set of 105 items). The heterogeneity of item selection, in this writer's opinion, tended to blur the interpretation of the results. Lateral dominance scales by Humphrey[54] and Crovitz and Zener[55] were lacking in reliability and validity data. The authors also failed to provide any justification for the inclusion or exclusion of items.

Several investigators have made systematic attempts to justify item selection for their questionnaire and provide some statistical reliability and validity data in support of

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53 Koch, <u>op. cit</u>., p. 117-221.

54 Humphrey, <u>op. cit</u>., p. 214-225.

55 Crovitz and Zener, <u>op. cit</u>., p. 271-276.

it usage. Hull[56] in 1936 was one of the first to do so in a study on laterality test items. Annett[57] in 1970 and Oldfield[58] in 1971 followed, presenting more sophisticated analyses.

Hull aimed at developing a questionnaire which was significantly valid and reliable. She began with a pool of forty either widely used or familiar items of unimanual handedness, organized these into two different sequences thus obtaining two different forms of the same questionnaire. The two forms were administered at over one month's interval to a sample of 160 students. A subsample of fifty subjects was asked to actually perform on two separate occasions the actions mentioned in the forty questionnaire items. Test-retest questionnaire and performance reliability data were obtained. Those items which were performed with the same hand by over 90% of the subjects and which elicited an identical side response from over 90% of the subjects on the questionnaire measure were considered sufficiently reliable to be included in a questionnaire measure of handedness. Fourteen items were thus selected. Responses to the

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56 C. J. Hull, "A Study of Laterality Test Items," in Journal of Experimental Education, Vol. 4, 1936, p. 287-290.

57 Annett, op. cit., 1970a, p. 303-321.

58 Oldfield, op. cit., p. 97-113.

questionnaire and performance measures on these fourteen items were then compared, using the actual performance as a validating measure. She found that in 90% of subjects twelve items elicited identical responses on the test-retest of both performance and questionnaire measures and on the comparison of the performance and the questionnaire measures. The high degree of relationship or agreement between the responses to each of those items warrants their inclusion in a handedness questionnaire.

The use of percentages of consistent response to establish item reliability left something to be desired in terms of refinement, a limitation which the author acknowledged.

Annett[59] attempted to empirically identify the main types of handedness. She selected twelve items requesting response in terms of unimanual preference. She failed to provide, however, any additional justification for this original selection of items. She administered this Handedness Research Questionnaire to over two thousand subjects, for the most part students at the University of Hull. The responses to the questionnaire were subjected to an association analysis, a technique developed by Williams and Lambert[60] for use in

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59 Annett, op. cit., 1970a, p. 303-321.

60 W. T. Williams and J. M. Lambert, "Multivariate Methods in Plant Ecology. I. Association Analysis in Plant Communities," in Journal of Ecology, Vol. 47, 1959, p. 83-101.

plant ecology. The purpose of Annett's analysis was to assess the degree of association of responses to any one item with responses to all other questions and thus to identify those items, the responses to which were most highly associated with all others. In this procedure, correlations between responses to all possible pairs of questions were calculated and summed for each question. This technique yielded indices of association between all questions, the reasoning being that those questions obtaining high indices of association would possess greater predictive validity as to the individual's direction and strength of hand preference than items with low indices of association. Greater weight could thus be given to some items in a handedness questionnaire. Her study underscored the differential contribution of a pool of items to the assessment of handedness.

Annett, however, failed to provide any reliability data for her questionnaire. Since seven of her twelve hand preference items were included in Hull's final questionnaire, one might surmise that little difficulty in demonstrating over-all reliability would be encountered.

Another investigator, Oldfield,[61] in 1971 attempted to provide a questionnaire that would yield an accurate and valid index of handedness. He employed a modified version

61 Oldfield, op. cit., p. 97-113.

of Humphrey's[62] inventory using its twenty items. He administered the questionnaire to a sample of eleven hundred individual adults and computed for each a laterality quotient (L.Q.) according to a slight modification of the formula (R-L)/(R+L) previously mentioned. Subsequently, he attempted to study the individual contribution of items to the laterality quotient value by summing "for each item, [...] scores for all subjects whose L.Q.'s place them in each of the L.Q. ranges."[63] A series of L.Q.'s for each item was obtained. The more closely the L.Q. for an item within each range (i.e., there were twenty ranges from -1.00 to +1.00), approximated the mean laterality quotient of subjects within each range, the greater the relation of the response pattern to that item with the total L.Q. and thus greater was deemed the contribution of that item to the L.Q. On the basis of the results of his item analysis, and on criteria of independence of sex differences, of socio-economic, geographical and cultural factors, Oldfield selected ten items from the original twenty. He admitted that the selection was still somewhat arbitrary as the results of the item analysis were not conclusive.

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62 Humphrey, op. cit., p. 214-225.

63 Oldfield, op. cit., p. 102.

In summary, only three investigators, Hull, Annett and Oldfield, have made systematic attempts to justify item selection for their hand preference questionnaires. The contributions and limitations of their studies were pointed out.

Assuredly, questionnaire assessment of handedness has been the target of much criticism. Barnsley[64] has summarized the main drawbacks of this approach:

1. Subjects, when young children particularly, are liable to response perseveration when the tests are lengthy. This limits the validity of questionnaires with this population.

2. Sampling: the assumption is always that an unbiased selection of population tasks with the hands is being included in the questionnaire.

3. Questionnaires generally lack standardization and result in subjective assessment.

4. The ensuing classification of handedness is generally too narrow and rigid to account and reflect all the potential variability of the handedness phenomenon.

He concluded suggesting that "the use of questionnaires of hand preference is a highly questionable technique."[65]

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64 Barnsley, op. cit., p. 21-22.

65 Ibid., p. 22.

Other investigators would disagree with this harsh assessment of the questionnaire method.

Hildreth[66] agreed with Barnsley's reservation regarding the use of the questionnaire technique with young children, yet maintained that with older children and particularly with adults, the questionnaire technique tends to be very reliable. Hull,[67] we have seen, demonstrated the reliability of some items as measures of handedness. Koch[68] using unimanual, bimanual, taught and untaught activities, found that the questionnaire was reliable as far as the total section scores were concerned: the reliability was highest for unimanual taught and was lowest for the bimanual untaught ones. Many investigators have sidestepped the whole issue of reliability of their handedness questionnaires. More data are needed. Bruml's[69] evidence previously quoted along with Koch's findings seem to suggest that unimanual activities tend to be much more consistent, and hence their measurement more reliable.

Many questionnaires have also failed to present either an adequate theoretical rationale or statistical validity data for their rather heterogeneous collection of items, and

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66 G. Hildreth, "The Development and Training of Hand Dominance: IV. Developmental Problems Associated with Handedness," in Journal of Genetic Psychology, Vol. 76, 1950, p. 85.

67 Hull, op. cit., p. 287-290.

68 Koch, op. cit., p. 127-135.

69 Bruml, op. cit., p. 12.

Barnsley's point about unbiased sampling of population tasks is well taken in many instances. Oldfield made several good points in this connection. No selection of items can be totally exempt from criticism.

> It should be emphasized that any set of items affords a view of handedness which is arbitrary, and that any measure of laterality has a validity which can extend no further than the data obtained from a reasonable sample population. Nevertheless such a procedure can prove useful for comparative purposes, provided a standard procedure is adhered to.[70]

His comments will remain relevant as long as there is insufficient understanding of the underlying mechanisms of handedness or of the criteria for inclusion and exclusion of items. Appropriately understanding and defining handedness is basic to a valid measurement of the concept. Procyk and Walker,[71] in 1967, comparing questionnaire, actual performance and pantomime assessments of handedness found correlations of .97 and .98 between these measures. They supported the use of questionnaires in terms of equal validity with actual performance measures adding that they were also more easily administrable and suitable for group use. The demonstration of validity for some items in studies by Hull,[72] Annett,[73]

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70 Oldfield, op. cit., p. 104.

71 M. Procyk and R. E. Walker, "An Empirical Comparison of Some Techniques for the Differentiation of Handedness," in Psychology in the Schools, Vol. 4, No. 4, 1967, p. 364-366.

72 Hull, op. cit., p. 287-290.

73 Annett, op. cit., 1970a, p. 303-321.

and Oldfield[74] also provided support for the valid use of the questionnaire assessment technique.

In summary, the questionnaire method appears to remain the most adequate to assess the continuum of preferential handedness. This review has underlined the importance of giving consideration to the following when this technique is employed in research: the provision of an adequate rationale for item selection, ensuring that the item pool represents a fair sampling of the handedness domain, that some standardization of procedure is achieved, and that an appropriate quantitative index discriminates between various degrees of preference. More data are needed to further support particularly the validity claims of both the method and of individual questionnaires.

B. The Assessment of Handedness as Hand Proficiency

Measurement of handedness as a hand proficiency variable has been accomplished through the use of a variety of motor tasks intended to measure the level of proficiency of each hand working independently. Some examples are given below. Heinlein,[75] in 1927, used simple coordination tests

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74 Oldfield, op. cit., p. 97-113.

75 J. Heinlein, "A Study of Dextrality in Children," in Journal of Genetic Psychology, Vol. 36, 1929, p. 91-119.

to study handedness: these were tapping, steadiness, dynamometer and target tests. Single and triple plate tapping, motility rotor, spool packer and pursuit rotor tests were employed by Beck.[76] Van Riper,[77] in 1934, developed his Critical-Angle-Board Test claiming to differentiate between thoroughly right-handed, thoroughly left-handed, and ambidextrous individuals on the basis of the angle at which subjects produced mirrored writing. Simon,[78] in 1964, measured a hand steadiness factor using a standard steadiness test involving a probe positioned in a hole. Annett,[79] in 1970, used a peg-board task to assess relative manual skill.

These investigators, for the most part, have chosen one or more motor tasks as adequate measures of a proficiency definition of handedness without providing any further rationale for their selection. Recently, several writers have attempted to identify some of the relevant dimensions of a proficiency definition of handedness using factor-analytical techniques. The investigations of Fleishman

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76 Beck, op. cit., p. 259-272.

77 C. Van Riper, "A New Test of Laterality," in Journal of Experimental Psychology, Vol. 17, 1934, p. 305-313.

78 J. R. Simon, "Steadiness, Handedness, and Hand Preference," in Perceptual and Motor Skills, Vol. 18, 1964, p. 203-206.

79 Annett, op. cit., 1970a, p. 312-313.

and Hempel[80] in 1954, Hempel and Fleishman[81] in 1955, Fleishman[82] in 1958, and Fleishman and Ellison[83] in 1962 were concerned with identifying the factors contributing to manipulative and other psychomotor skills without directly relating these to handedness. These dimensions of manipulative ability seem relevant to the measurement of a proficiency definition of handedness. Their studies yielded the following factors fairly consistently using apparatus tests: finger dexterity, manual dexterity, speed of arm movement, arm-hand steadiness, and reaction time. Other factors of more limited scope were wrist-finger speed and aiming, and seemed best measured by printed tests.

Palmer,[84] in an as yet unpublished paper, conducted a factor-analytic study of behavioral measures of hand proficiency in an effort to isolate relevant dimensions of

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80 E. A. Fleishman and W. E. Hempel, "A Factor Analysis of Dexterity Tests," in Personnel Psychology, Vol. 7, No. 1, 1954, p. 33-39.

81 W. E. Hempel and E. A. Fleishman, "A Factor Analysis of Physical Proficiency and Manipulative Skill," in Journal of Applied Psychology, Vol. 39, No. 1, 1955, p. 12-16.

82 E. A. Fleishman, "Dimensional Analysis of Movement Reactions," in Journal of Experimental Psychology, Vol. 55, 1958, p. 438-453.

83 E. A. Fleishman and G. D. Ellison, "A Factor Analysis of Fine Manipulative Tests," in Journal of Applied Psychology, Vol. 46, No. 2, 1962, p. 96-105.

84 Palmer, op. cit., 1967, p. 1-16.

differentiation in handedness. He selected twenty tests which lent themselves easily to the assessment of proficiency with each hand separately, keeping in mind that tasks using large and small muscles should be included. Along with the usual tapping, dynamometer and accuracy tests, some very unusual measures of motor ability, such as the time required to write one's name, the size of the handwriting, time to write the digits one to ten and their size, the differential circumference of the tensed and normal bicep, and others were selected. The analysis yielded six principal component factors of which only one was interpretable. It was labelled "Focussed application of power and strength." All but one of the twenty tasks loaded on this factor. A normal-varimax rotation of the four principal component factors gave the following results: the first rotated factor was virtually identical to the one described above; the second appeared to possess some conceptual validity and was labelled "precision control in fine hand movements." Rotated factors three and four were not readily interpretable. This study seems to add little to our understanding of the factorial dimensions of handedness since the only two interpretable factors were extremely general in nature. An inauspicious selection of tasks may have been partly responsible.

Barnsley and Rabinovitch,[85] in 1970, hoped that a factor analysis of a wide variety of motor tests, thirty-two in all, would yield an adequate operational definition of preferred-non-preferred hand performance. Many of the tests were selected with an eye to measure the factors identified in the Fleishman, Hempel and Ellison studies; others were included on the basis of relevant studies and a few selected for intuitive reasons. The order of test presentation was randomized for each subject. All tests except three were administered twice to each hand in a preferred, non-preferred, non-preferred, preferred counterbalanced order.

The factor analysis using a sample of fifty males and fifty females, mostly undergraduate students, resulted in nine interpretable factors of hand performance accounting for 73% of the variance: reaction time, speed of arm-movement, wrist-finger speed, arm-hand steadiness, arm-movement steadiness, aiming, a motivational factor, finger tapping, and dexterity. Each factor was common to male and female and to preferred and non-preferred hand performance. The identified factors closely resembled those of Fleishman and his associates and shed favorable light on the reliability of these dimensions of hand skill. Barnsley and Rabinovitch, however, failed to find support for the distinction made in the Fleishman studies

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85 Barnsley and Rabinovitch, op. cit., 1970, p. 343-362.

between finger and hand dexterity. The dexterity factor reported in this study was similar to a combination of the two dexterity factors obtained by the previous investigators. This study also demonstrated that differences in skill between the preferred and non-preferred hands were quantitative not qualitative. They found quantitative skill differences between the preferred hand, or P hand, and the non-preferred hand, or NP hand, on all factors of hand performance except reaction time and speed of arm movement. They drew the conclusion that handedness was "a single dimension characterized by superior performance of the preferred hand."[86] This conclusion, however, failed to account for proficiency scores on at least two relevant dimensions of hand skill and should be considered tentatively pending further investigations.

Barnsley[87] in 1971, pursuant to the previous experiment, set out to identify the factors of preferred and non-preferred hand performance in children and to develop an appropriate technique for measuring handedness. Hand skill tests were selected to represent all the factors of P and NP hand performance identified by Barnsley and Rabinovitch, and other relevant dimensions suggested in the literature. Thirty-three tests were administered to a sample of 50 seven year old

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86 Ibid., p. 360.

87 Barnsley, op. cit., p. 31-59.

boys and an equal number of seven year old girls. The order of presentation of the tasks was, as in the previous study, randomized for each subject. Similarly, each task was performed twice by each subject in the same counterbalanced order.

The results of all tests were factor-analyzed according to the principal component method. Seven main factors were obtained: wrist-finger speed, arm-movement steadiness, finger tapping, aiming, arm-hand steadiness, reaction time, and strength. The results were similar to those obtained in the previous study and further supported the reliability of these factors. Several differences were noted: the absence of dexterity and speed of arm-movement factors in grade one children, and the added dimension of hand strength as a significant factor in this age group.

This study supported Barnsley and Rabinovitch's contentions that skill differences between the hands for both sexes are quantitative not qualitative, and that hand skill on the majority of factors is characterized by superior P over NP performance. Performance on the reaction time factor is the notable exception as in the previous study. No differences between P and NP hand levels of skill were found. Barnsley concluded that these results supported the view of handedness as a "single-dimensioned phenomenon."[88]

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88 _Ibid._, p. 56.

On the strength of these results and those of the previous investigation, Barnsley developed a performance scale for handedness which would be applicable to a wide age range. The reaction time and movement time tests were not included since they failed to conform to the operational definition of handedness requiring superior P over NP hand skill. Included in the battery were tests measuring the five factors of hand skill common to adults and children. Tapping Small Time was chosen to measure Wrist-Finger Speed; Tapping Small Errors selected to measure Aiming; Hand Steadiness Duration to measure Arm-Hand Steadiness; Vertical Movement Steadiness Duration to measure Arm-Movement Steadiness; and Finger Tapping Long 1-30 to measure Finger Tapping. In the adult battery, the Grooved Peg Board was selected to measure the Dexterity factor, while the Dynamometer was chosen to measure the Strength factor in the battery for children. The author noted that several tests which evidenced sufficiently high reliability were usually available to measure each of the dimensions of hand skill.

Barnsley's exclusion of the reaction time tests was consistent with his operational definition of handedness. The procedure seems questionable, however, since it amounts to disregarding reliable data, e.g., measures of the reaction time factor, because these are discrepant with his theoretical position.

The studies reviewed in this section have pointed to a limited number of reliable factors of hand skill. The batteries of motor tests developed by Barnsley for adults and children constitute pioneering attempts to systematically measure these dimensions.

The problem of representing quantitatively an individual's level of hand proficiency has been met in several ways. The most frequently utilized index has been the difference between the performance scores of right and left hands. When only one motor test was given, this index most simply and directly represented "relative" manual proficiency. The studies by Simon[89] and Annett[90] provide examples of its use. A performance index such as the one utilized by Durost has also been utilized. This index was computed in exactly the same way as the hand preference index (R-L)/(R+L), with the difference that the proficiency scores on a given task are substituted and not the number of tasks preferred with one and the other hands. Durost's handedness index is "the proportion the difference in achievement of the two hands is to the total achievement on a given test, represented by the sum of the scores of the two hands."[91] One major advantage

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89 Simon, op. cit., p. 203-206.

90 Annett, op. cit., 1970a, p. 303-321.

91 Durost, op. cit., p. 238.

of this formula is that the distribution of proficiency indices is limited in range from -1.00 to +1.00.

When relative manual proficiency is to be measured by two or more motor tests, a difficulty arises in the computation of a single index of relative proficiency. Investigators have met this problem in various ways. Beck[92] used the average percentile ranks to group the right-left difference scores on the motility rotor, triple tapping, and pursuit rotor tasks. Buxton[93] one year later computed proficiency ratios on each test for each subject, using Durost's index. A composite motor score was obtained for each subject by averaging the percentile scores of ratios on each test. In both studies, the averaging of percentile motor ranks entailed the error of adding unequal units. Percentile scores are given on an ordinal and not an interval scale.

Barnsley,[94] using a battery of six motor tasks, employed a novel treatment of the performance scores. The tests were administered twice to each hand yielding two

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92 Beck, op. cit., p. 267-268.

93 C. E. Buxton, "A Comparison of Preference and Motor-Learning Measures of Handedness," in *Journal of Experimental Psychology*, Vol. 21, 1937, p. 465-466.

94 Barnsley, op. cit., p. 63-67.

preferred hand and two non-preferred hand scores. These were summed producing separate preferred and non-preferred hand performance scores for each test. Measures of "overall" preferred hand proficiency and "overall" non-preferred hand proficiency were computed in the following way: all scores were converted to standard scores and included in a single sample. When appropriate, standard scores were reflected about the mean (operationally multiplied by -1) in order that high scores indicate superior performance on all variables. Conversion to McCall T scores was the next step. Those values representative of preferred and non-preferred hand performance were then summed separately for each subject across all six variables yielding the "overall" measures suggested above. An identical analysis was employed by Barnsley and Rabinovitch[95] in a very recent study. Measures of "overall" relative proficiency were obtained in Barnsley's earlier study in several ways which were shown to be approximately equivalent: notably by calculating for each subject the difference between his "overall" preferred and "overall" non-preferred hand scores.

The use of standard scores in the computation of "overall" measures of hand skill definitely represents a statistical improvement in that the problem of adding unequal units is circumvented. Another advantage of this method

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95 Barnsley and Rabinovitch, op. cit., 1973, p. 7-15.

is that it yields separate measures of preferred, non-preferred as well as a measure of relative motor proficiency for each individual.

The use of skill differences between the hands to assess handedness raises scaling issues which have been largely overlooked by investigators. The use of difference scores is appropriate only when one's measurements are on an interval scale. An illustration: the hand dynamometer. Hand scores are read and recorded in kilograms. Is the strength difference indicated by scores of 20 and 25 kilograms identical to that pointed to by scores of 25 and 30, or 30 and 35 kilograms? If not, strength scores are not represented on an interval scale and strength differences as reflected by kilogram differences are not precisely comparable. Similar errors may also accrue in the use of difference scores from such frequently employed measures of hand skill as the peg board tasks, finger tapping speed, hand coordination, and steadiness tests. When overall indices of skill are computed, the imprecisions inherent in the separate sets of difference scores are probably compounded.

In addition, their validity has recently been called into question by Barnsley.[96] He found low positive correlations between preferred hand and difference scores and

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96 Barnsley, op. cit., p. 69-70.

moderate negative correlations between non-preferred hand and difference scores, thereby suggesting that the proficiency of the non-preferred hand accounted for a higher percentage of the variance in the difference scores than did the preferred hand level of skill. This failed to support Palmer's[97] developmental view of increasing differentiation between preferred and non-preferred hand skill, and Barnsley and Rabinovitch's[98] hypothesis that overlearning of skills in the preferred hand is basic to the phenomenon of handedness. On the strength of that result, and the finding that the ability to automatize simple behaviors was significantly related to preferred hand performance, Barnsley argued that handedness should be defined by the level of preferred hand performance, rather than by the degree of skill differences between the hands.

In summary, indices of differential skill and recently of preferred hand skill have been employed to quantitatively represent the hand proficiency variable. Barnsley found little relation between indices of preferred hand and relative skill. Further investigation of the relationships between these indices is warranted.

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97 Palmer, op. cit., 1964, p. 257-259.

98 Barnsley and Rabinovitch, op. cit., 1970, p. 361

Consideration of the dimensions of hand skill, of their measurement and quantitative representation raises the issues of reliability and validity of these measurements. A discussion of these follows.

A limited number of authors have provided reliability estimates of their measures of hand skill. Koch,[99] using a Smedley hand dynamometer, found this measure of the relative difference in hand strength to be not very reliable. With a sample of fifty subjects, she obtained a test-retest rank correlation of performance differences of only .58. Buxton[100] obtained on three tests previously employed by Beck, the pursuit rotor, triple-plate tapping and the motility rotor, moderate odd-even coefficients of reliability varying from .69 to .89 when corrected for full-length tests using the Spearman-Brown formula. Burge[101] estimated the reliability of hand strength, accuracy and speed dimensions of skill using the hand dynamometer, throwing at a target and bouncing a ball tests, respectively. The high test-retest correlation found on the strength test (r is .94) is contrary to Koch's

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99 Koch, op. cit., p. 188.

100 Buxton, op. cit., p. 467.

101 I.C. Burge, "Some Aspects of Handedness in Primary School Children," in British Journal of Educational Psychology, Vol. 22, 1952, p. 45-46.

results. A similarly high reliability figure was obtained for the speed test (r is .92) while the accuracy test yielded a moderate coefficient (r is .75). Palmer[102] found a moderately high reliability coefficient of .83 for the main factor of "focussed application of power and strength" derived from his factor-analytic study. Barnsley[103] provided reliability estimates for all thirty-three motor tests employed in his factor-analytical study. The test-retest coefficients were generally in the moderate to high range. The reliabilities of those tests finally selected for inclusion in his handedness battery varied from .64 to .95. The high consistency of scores on the hand dynamometer test (r is .95) was noteworthy and agreed with the findings of Burge's study.

Recent evidence supported at least moderate reliabilities for those skill tasks which measure relevant dimensions of hand proficiency.

The question of validity of the proficiency measures of handedness has been raised in terms of the consistency of what is measured by the various tests employed. Is there a central motor skills factor that these tests can measure or are the latter tapping task-specific abilities? Durost obtained positive correlations between all his handedness

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102 Palmer, op. cit., 1967, p. 9.

103 Barnsley, op. cit., p. 33-39.

measures ranging from .28 to 1.00 and concluded that "handedness, as measured by objective tests of this nature, is essentially unitary and not specific to the type of test."[104] Beck[105] arrived at a similar conclusion of a common laterality factor. Correlations between difference scores obtained on five motor measures ranged from .41 to .71. Barnsley and Rabinovitch[106], it was mentioned above, supported the unidimensionality of handedness. Although the P hand evidenced superior performance on all tasks, no indication was given that the level of P hand performance on any one task was closely related to the level of P hand performance on the others. Similarly, no data on the relation between P-NP levels of skill on each of the selected motor tasks were provided.

Buxton[107] obtained results in sharp contrast with those reported above. Intercorrelations between the difference scores on three motor measures ranged from .06 to .14. In a recent study, Bruml[108] found correlations ranging in absolute value from .03 to .62 between difference scores on

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104 Durost, op. cit., p. 327.

105 Beck, op. cit., p. 269.

106 Barnsley and Rabinovitch, op. cit., 1970, p. 360.

107 Buxton, op. cit., p. 467.

108 Bruml, op. cit., p. 10-12

five motor skill tasks. These results were obtained with samples of kindergarten, grade 2 and grade 4 children, where they may be more subject to developmental influences than with adults. Similarly, Burge[109] found little or no relation between abilities tested by three different motor tasks, measuring strength, accuracy and speed for a group of fifty dextral boys. Hildreth[110] also suggested that performance may be uneven from one motor task to another, without providing any supporting data however.

Singer[111] reviewed some research questioning the concept of a general motor ability and provided some supportive evidence for the notion that performance is task-specific rather than general. Provins[112] in 1967, reviewing research on motor proficiency in terms of the underlying organization of motor skills, acknowledged that most skills are specific to certain tasks. He admitted, however, that a limited amount of generalization of skill to other motor performances on the

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109 Burge, op. cit., p. 48

110 G. Hildreth, "The Development and Training of Hand Dominance: II. Developmental Tendencies in Handedness," in Journal of Genetic Psychology, Vol. 75, 1949, p. 239.

111 R. N. Singer, "Interlimb Skill Ability in Motor Performance", in American Association for Health, Physical Education and Recreation Research Quarterly, Vol. 37, 1966, p. 406-410.

112 Provins, op. cit., p. 146

basis that sequences of skilled movements will be common to many different activities. Kaplan agreed with the above: on the strength of Buxton's findings mainly, reported above, he asserted:

> Despite the occurrence of considerable presumption to the contrary, the laterality manifestations of different specific motor activities--e.g., as utilized to determine hand dominance--lack general correlation with each other. Thus, laterality manifestations do not involve merely a single general or central laterality factor.[113]

This statement appeared somewhat gratuitous, however, in the context of a rather cursory review of the literature.

The use of a heterogeneous battery of tests to measure a proficiency definition of handedness becomes highly questionable in the light of the above data and discussion. Measures of hand skill do not seem to be equally useful and valid. The need for further factor-analytic studies of motor proficiency seems evident if the relevant dimensions of hand skill are to be reliably identified and appropriate measures of these found. Whether handedness can be operationally defined as a single dimension characterized by superior preferred over non-preferred performance on relevant factors of hand skill, or whether these factors of skill are discrete and only remotely related, is very much an unresolved issue.

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113 Kaplan, op. cit., p. 371

In this section, several reliable dimensions of hand skill were identified and their measurement discussed. Some researchers have raised doubts about the validity of a measurement of handedness as proficiency, the central issue being to what extent there exists a common substrate to individual hand skill measures.

A discussion of the assessment of hand preference and hand proficiency variables is now complete. In a final section of this review, studies which have previously explored the relation between these variables will be summarized.

4. Relationship between Preference and Proficiency Measures of Handedness.

The review of the relationship between preference and proficiency measures of handedness will begin with a comparison of the distributions of preference and skill. Subsequently studies directly relating these two variables will be appraised.

A. A Comparison of Preference and Proficiency Distributions

Quantitative assessments of hand preference obtained from questionnaire measures have yielded fairly consistently a bimodal and roughly J-shaped distribution. Studies by

Durost,[114] Lauterbach,[115] Crovitz and Zener,[116] Oldfield,[117] and Annett[118] support this contention. Several investigators, including Annett[118b] and Oldfield[118c], have reported differences in the preference distributions of males and females: greater proportions of males tend to be classified as left-handed; conversely, more females prefer their right hand.

The literature evidences much less agreement when the distribution of handedness according to proficiency measures is concerned. Woo and Pearson,[119] in 1927, found that the differences in strength between both hands were normally distributed. Durost's findings were in direct contradiction of the above. He concluded:

> No one curve type describes all the test distributions. Rather, the shape of the distribution curve seems to be in part at least a function of the type of test used. [...] All curves are skewed and the direction of the skewness is negative in all cases except the Target Test. As the tests require finer and finer

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114 Durost, op. cit., p. 306-307.

115 Lauterbach, op. cit., p. 208

116 Crovitz and Zener, op. cit., p. 271-276.

117 Oldfield, op. cit., p. 100 and p. 105

118 M. Annett, "The Growth of Manual Preference and Speed," in British Journal of Psychology, Vol. 61, No. 4, 1970b, p. 554.

118b Ibid., p. 553

118c Oldfield, op. cit., p. 105

119 Woo and Pearson, op. cit., p. 165-199

> coordinations the negative skewness becomes more marked and the left-handed end of the distribution takes on more of the characteristics of an independent distribution. All distributions are leptokurtic. Perhaps the most important conclusion concerning the distributions of handedness is that they show no evidence of being normal curves.[120]

Beck[121] found conflicting results on two motor tasks: the distribution of difference scores on the spool packer was symmetrical and approximated the normal curve while scores on the motility rotor gave a negatively skewed distribution tending toward bimodality. These findings support Durost's contention that the distribution curve is in part a function of the test used. Annett[122] found the distribution of difference scores on a peg board test symmetrical and approximating a normal curve, thus providing recent support for Pearson and Woo's position.

According to the preference distribution, consistent left- and consistent right-handers are asymmetrical from the point of maximum inconsistency to approximately equal extents,[123] although Durost[124] and Oldfield[125] found the

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120 Durost, op. cit., p. 326.

121 Beck, op. cit., p. 263-266.

122 Annett, op. cit., 1970b, p. 550.

123 Ibid., p. 554

124 Durost, op. cit., p. 306-307.

125 Oldfield, op. cit., p. 108.

rise toward consistency to be different on the right and left sides. When performance measures are employed, however, the point of equal skill or no difference between the hands is slightly, but distinctly, to the left of the distribution mean or median as demonstrated in the works of Beck,[126] Hildreth,[127] and Annett.[128] If the distribution of difference scores is negatively skewed or bimodal, then the range of difference scores can still be identical on both sides of the point of no difference. However, if the distribution is normal and symmetrical, then scores where the right hand exceeds the left would cover a wider range than would scores where the left hand performances exceed the right. Accordingly, left-handers would never achieve the degree of left over right superiority in actual skill which is characteristic of those right-handers at the right end of the distribution of difference scores. If the normal distribution hypothesis is correct, then it appears that left-handers could be as consistent in their preferences as right-handers but would not achieve the superior degrees of relative skill. This intimates a less than perfect correlation between the

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126 Beck, op. cit., p. 263-269.

127 Hildreth, op. cit., 1949, II, p. 242-243.

128 Annett, op. cit., 1970b, p. 550.

preference and relative hand skill variables. Further research is needed.

Differences between the skill distributions of males and females have also been reported: Annett[128b] found R-L skill scores on a peg-moving task to be larger in females than in males; Barnsley and Rabinovitch found that females were better with both their preferred and non-preferred hands on "tasks demanding finely controlled and accurate movements";[128c] as a group, they recorded superior scores on steadiness, aiming and dexterity factors. The performance of men was better with both hands on "tasks involving quick, gross movements":[128d] on finger tapping and speed of arm movement tasks. Men were also obviously superior in grip strength. It is important to note that differences reported as a function of sex by these authors were quantitative and not qualitative.

Comparing the J-shaped bimodal distribution of preference and the variety of distributions, including

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128b Annett, op. cit., 1970b, p. 553.

128c Barnsley and Rabinovitch, op. cit., p. 360.

128d Ibid., p. 360.

unimodal normal, unimodal skewed and leptokurtic, and bimodal skewed,[129] obtained to describe relative proficiency, little similarity is immediately obvious. The heterogeneity of proficiency distributions suggests less commonality in what is measured by the proficiency measures than what is tapped by the preference questionnaires. These various proficiency distributions add some credibility to the specificity theory of motor functioning. The problem of relating a distinctly J-shaped preference distribution to the various proficiency distributions is a real one which has yet to be satisfactorily elucidated. The influence of the sex variable in hand preference and hand proficiency need also be further investigated.

B. Studies Relating Hand Preference to Hand Proficiency Measures

The studies reviewed herein will be grouped according to their contribution to two headings: studies of the relation between preferred and most proficient hand, and studies

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129 Beck, op. cit., p. 263-266.

of the relation between hand preference measures and relative skill scores.

(a) Studies of the Relation between Preferred Hand and Most Proficient Hand.- The assumption of superior skill of the preferred over non-preferred hands may seem hardly questionable. The evidence here is inconclusive. Provins'[130] theory that superior skill results from more extensive use of one preferred hand would corroborate this position. Simon[131] found preferred hand scores to be superior to non-preferred hand scores on a steadiness task for a sample of self-classified right- and left-handers. Further analyses revealed, however, that superior P hand performance held only for the right-handed group. Smith and Lewis[132] in 1963, comparing P and NP hand performance in a sample of seven to ten year old boys, found significant differences in contact times (i.e., average time spent in contact) of preferred and non-preferred hands on a hand steadiness task. No difference was found, however, in the number of contacts of P and NP hands. Barnsley[133] reported 99% accurate discrimination of right- and

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130 Provins, op. cit., p. 146-147.

131 Simon, op. cit., p. 204-205.

132 L. E. Smith and F. D. Lewis, "Handedness and Its Influence on Static Neuromuscular Control," in American Association for Health, Physical Education and Recreation Research Quarterly, Vol. 34, 1963, p. 206-212.

133 Barnsley, op. cit., p. 61-68.

left-handers, classified according to their preferred hand for writing, on the basis of superior hand performance on his battery of motor tests.

While studies by Beck[134] in 1936 and Benton, Meyers and Polder[135] in 1962 provide evidence of an over-all trend toward superior preferred hand skill, they also indicate over-all fairly poor discrimination of self-classified right- and left-handers on the basis of proficiency scores. There is considerable overlap between the distributions of P-NP scores of right- and left-handers. Kimura and Vanderwolf[136] in 1970 found the non-preferred hand to be as skillful as the preferred hand in left-handers and more skillful than the preferred hand in right-handers in the ability to perform fine finger movements.

A different hand skill pattern for right- and left-handers has been underscored: Simon[137] concluded that more left-handers than right-handers are incorrectly classified on the basis of superior hand performance. The most skillful hand seems a much more reliable predictor of the preferred

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134 Beck, op. cit., p. 262-269.

135 Benton et al., op. cit., p. 326-327.

136 D. Kimura and C. H. Vanderwolf, "The Relation between Hand Preference and the Performance of Individual Finger Movements by Left and Right Hands," in Brain, Vol. 93, 1970, p. 769-774.

137 Simon, op. cit., p. 205.

hand for dextrals than for sinistrals. The slower rise toward consistent left-hand preference mentioned earlier seems related to a slower rise toward definite or clear-cut left- over right-hand superior skill for left-handers. Many left-handed subjects in studies by Beck,[138] Benton, Meyers and Polder[139] and Annett[140] were found to be much more dextral on criteria of skill than subjects claiming right-hand preference.

Several factors pertaining to the proficiency measures have been cited in that they seem to contribute to increasing the discrimination between hand preference groups. Task complexity is one factor. When more complex tasks,[141] tasks requiring finer manual coordination,[142] were employed, there resulted a greater though far from perfect agreement between the most proficient and preferred hands. The number of motor tasks employed may be another contributing component: the most proficient hand as determined by several measures, agreed more frequently with the preferred hand than was the case

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138 Beck, op. cit., p. 262-269.

139 Benton et al., op. cit., p. 326-328.

140 Annett, op. cit., 1970a, p. 316.

141 Beck, op. cit., p. 269-270.

142 Durost, op. cit., p. 326.

when the most proficient hand was predicated on the results of only one test.[143]

Over all, previous studies have suggested less than perfect agreement between the preferred and most skillful hand. Some differences between dextrals and sinistrals were indicated.

(b) Studies of the Relation between Hand Preference Measures and Relative Skill Scores.- Burge[144] investigated the relation between relative proficiency measures on strength, accuracy, and speed tests and a three-way classification of preference; i.e., dextrals, sinistrals, and dextro-sinistrals. These groups contained right-handers and left-handers consistent in their preference on four activities, and handers more or less inconsistent in their preference. A lack of discrimination within the inconsistent handedness group is immediately obvious. Relative proficiency scores tended to be largest in the right-handed and smallest in the dextro-sinistral groups across all measures. There is some indication here that inconsistency in preference is associated with smaller degrees of relative dexterity between the hands.

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143 R. H. Ojemann, "Studies in Handedness: I. A Technique for Testing Unimanual Handedness," in Journal of Educational Psychology, Vol. 21, No. 8, 1930, p. 610-611.

144 Burge, op. cit., p. 45-51.

Similar results were found by Palmer[145] in an unpublished study: right-handers consistent in preference for one hand on twenty measures of proficiency were found to yield higher "specialization scores," or P-NP scores, than did both the left- and mixed- (or inconsistent) handers. Left-handers were found to be more "specialized" than mixed handers. Once again, some relation between degree of consistency of preference and degree of relative unimanual skill was pointed to.

Gillies, MacSweeney, and Zangwill, in 1960, comparing the P and NP hand performances of a group of ten inconsistent left-handers, i.e., subjects who wrote with their left hands and performed other unimanual activities such as throwing or holding a racket with the right hand, found that on a writing test, the "speed and quality of writing with the non-preferred (right) hand were, in general, but little inferior to the performance with the preferred hand, testifying to appreciable ambidexterity."[146] These authors support a relation between inconsistency in hand preference and lesser levels of differential hand skill.

Benton, Meyers and Polder[147] found that left- and right-handers, consistent in their preference for one hand in

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145 Palmer, op. cit., 1967, p. 10.

146 S. M. Gillies, D. A. MacSweeney, and O. L. Zangwill, "A Note on Some Unusual Handedness Patterns," in Quarterly Journal of Experimental Psychology, Vol. 12, 1960, p. 114-115.

147 Benton et al., op. cit., p. 326-327.

three activities, obtained higher average P-NP scores on the Small Parts Dexterity Test than did corresponding groups of right- and left-handers inconsistent in their preference for one hand on one or more of the activities.

These various studies repeatedly suggest that the introduction of the consistency of preference dimension increases the degree of association between relative proficiency and preference measures.

Simon, however, failed to find any differences in P-NP scores of groups of consistent and inconsistent left-handers on a steadiness task. Only five randomly selected items were included in the assessment of preference and an inconsistent hander was one "who reported using the right hand for one or more of the activities covered by the pre-test questionnaire."[148] He compared nine inconsistent handers and fifteen consistent handers, all self-classified strongly left-handed subjects. That the "inconsistent" handers of this study were not at all very inconsistent in hand preference seems plausible. In addition, Simon failed to report the actual mean difference scores of the consistent and inconsistent handers; possibly the relative magnitudes of the P-NP scores of the two groups were in the direction predicted by preceding investigations.

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148 Simon, op. cit., p. 205.

The studies mentioned above compared the relative dexterity scores of groups of handers; i.e., right, left, and ambidextrous groups, consistent and inconsistent groups. The criteria for inclusion into one or the other group were frequently somewhat arbitrary and entailed artificial divisions in the continuum of hand preference.

Buxton[149] was one investigator who attempted to directly relate measures of relative skill to measures of degree of consistency in hand preference. The assessment of preference was made on the basis of observations of hand usage in several unimanual tasks. Use of the right and left hands was weighted +1 and -1, respectively. Scaled scores of hand preference could vary from +50 to -50. He found correlations varying between .22 and .40 between the index of hand preference and the performance ratios obtained on each motor task. When the performance ratios were pooled into a composite score, the correlation increased to .45. This led the author to the conclusion "that although there is a definite relationship between the two types of tests when the batteries each are pooled, the two types of tests are in general sampling behavior determined by many factors not common to both."[150] These results should be interpreted with caution since the

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149 Buxton, op. cit., p. 464-469.

150 Ibid., p. 468.

method of assessment of hand preference was both unusual and lacking in standardization.

Koch,[151] using her 105-item questionnaire to assess hand preference, found practically negligible correlations between measures of hand strength and relative strength of hand preference. These findings need be qualified in view of the reservations expressed previously regarding the length and heterogeneous item selection of this preference questionnaire. The author also acknowledged the potential lack of precision of her measurements of hand strength.

In her association analysis, Annett[152] found approximately two dozen patterns of response to the questionnaire items ranging from consistent left-handedness to consistent right-handedness. Having acknowledged that the distribution of preferences is a continuous one and should not be discussed in discrete right-left categories, she asserted, nevertheless, that for most cases a fourfold classification of handers would suffice: consistent right-handed, inconsistent right-handed, inconsistent left-handed and consistent left-handed. Using this classification, she demonstrated graphically an approximately linear relation between the continua of hand preference and relative skill on a peg board task for

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151 Koch, op. cit., p. 187-188.

152 Annett, op. cit., 1970b, p. 551.

populations varying in age from 3-1/2 to 15. Consistent right-handers obtained greater average (R-L) difference scores than inconsistent right-handers and similarly consistent left-handers obtained greater mean (L-R) difference scores. No statistical measures were employed to further describe the nature of this relation or the degree of common variance. The use of a quantitative measure of hand preference, to describe the twenty-three categories mathematically, would have permitted a more thorough statistical analysis of the results.

The findings are inconclusive. Though most studies support some relation between preference and relative skill measures, the nature and extent of this relationship is unclear.

The notion that degree of preferred hand proficiency may more adequately represent a performance definition of handedness was recently emphasized by Barnsley[153] in 1970 and Barnsley and Rabinovitch[154] in 1973. This writer is unaware of any study, however, which has systematically investigated to date the relation of degree of proficiency of the better hand to measures of hand preference. The present research will attempt to speak to this issue.

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153 Barnsley, op. cit., p. 66-74.

154 Barnsley and Rabinovitch, op. cit., 1973, p. 7-9.

5. Summary and Statement of Hypotheses.

This review of the literature began by emphasizing the variety of operational definitions of handedness and underscoring the conceptual confusion associated with this phenomenon. The next section attempted to develop a theoretical rationale in order to critically evaluate definitions of handedness. Some theoretical support for both preference and proficiency definitions of handedness was found. The importance of investigating the relationships between these two definitions was evidenced. A discussion of methods of assessment of hand preference and hand skill provided a basis from which to appraise those studies which had previously investigated the relationship between these variables.

The critical review suggests the following conclusions:

1. There has been a dearth of theoretical and experimental effort toward appropriately defining and measuring the handedness variable. Many definitions have been volunteered which presume to measure adequately the handedness phenomenon.

2. The preference and proficiency definitions of handedness were supported on a theoretical level; they have also been most extensively used by researchers.

3. While preference and proficiency definitions of handedness seem related theoretically, the degree of common variance between measures of these definitions is unclear.

4. Proficiency definitions of handedness as the level of differential hand skill and level of preferred hand skill both claim support in the literature. Further investigation of their interrelation as well as their relation to hand preference seems of value.

5. It may be that the preference and performance definitions of handedness describe different yet complementary components of the larger phenomenon of handedness.

6. Both dimensions of consistency of preference and of hand skill are matters of degree; they both should be measured as such to enable a finer and more precise study of their interrelation.

The main problem under investigation in this study is the extent to which preference and proficiency definitions of handedness represent or describe equivalent phenomena. The general hypotheses which will be put to the test are the following stated in null form:

1. There is no significant relationship between the preferred hand and the most proficient hand on hand skill measures.

2. There is no significant relationship between measures of handedness as consistency of preference and as the level of differential hand skill.

3. There is no significant relationship between measures of handedness as consistency of preference and as the level of preferred hand skill.

4. There is no significant relationship between measures of handedness as the level of differential hand skill and as the level of preferred hand skill.

The first chapter has demonstrated the importance of further research to compare various operational definitions of handedness. In the next chapter, the method of the experiment[155] designed to investigate the above will be described in detail.

155 The word 'experiment' is not given throughout this thesis its strict meaning which implies the manipulation of at least one independent variable. It is used here as a synonym for such terms as research, investigation or study.

CHAPTER II

EXPERIMENTAL DESIGN

In this chapter the tools, the sample, and the method of the experiment will be described in turn, followed by a restatement of the specific hypotheses. The statistical operations employed in the analysis of the data are presented subsequently.

1. The Tools of the Experiment.

Tools used in the measurement of the hand preference variable will be described first and those employed in the assessment of the hand skill variable will be reported subsequently.

The hand preference variable was measured in this study on a continuous scale using a slightly modified version of Annett's Handedness Research Questionnaire 2.[1] Since no questionnaire reviewed in the previous chapter met all the criteria set down for an adequate measure of hand preference or has gained wide acceptance and use, the selection of this measure was justifiable on the basis of the following: that it provided data on the relative value and discriminating ability of various items, that it lent itself easily to the

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1 M. Annett, "A Classification of Hand Preference by Association Analysis," in British Journal of Psychology, Vol. 61, No. 3, 1970, p. 321.

computation of an index of preference on a continuous scale, and that many items finally selected by Annett were also included in the Hull[2] (7 of 12 items) and Oldfield[3] (6 items of 10) inventories. A previously expressed criticism of the study mainly in terms of an inadequate rationale for the original selection of items may be reiterated. It is recognized that cross-validation studies of this questionnaire are needed.

The Handedness Research Questionnaire 2[4] consists of twelve items on which an association analysis was performed. Six items, highly associated with all others, were termed primary questions and were given greater weight in the scoring. They are items A, B, C, D, J, and K. A second band of items, less highly associated with all others, was referred to as secondary questions. They are questions E, F, G, H, and I. Question L evidenced low overall association with other items and will be omitted in this study.

In order to counterweigh a possible social desirability factor loading toward the right-handed end of the handedness continuum, the eleven items of Annett's questionnaire were

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2 C. J. Hull, "A Study of Laterality Test Items," in Journal of Experimental Psychology, Vol. 4, 1936, p. 287-290.

3 R. C. Oldfield, "The Assessment and Analysis of Handedness: The Edinburgh Inventory," in Neuropsychologia, Vol. 9, 1971, p. 97-113.

4 A copy is found in Appendix 1.

interspersed with items requesting other pertinent physical data from each subject. This modified version of Annett's inventory contained twenty-seven items and was labeled the Physical Data Questionnaire.[5] On each relevant hand preference item, the subject was requested to select one of three answers, i.e., Right, Left, and Either. Since it may be tempting to adopt a response set in completing this type of paper-and-pencil questionnaire, the order of presentation of the right and left alternative answers to each question was systematically alternated. It was felt that this procedure should maximize the probability of identifying handers inconsistent in their preference.

The following objects were used in the actual performance of the actions specified by the items of the hand preference questionnaire: a pencil, a tennis ball, a tennis racket, matches, scissors, a needle and thread, a broom, a shovel, a deck of cards, a hammer, and a toothbrush.

Past researchers have assessed the dimension of hand skill using a wide spectrum of motor tests. Recent factor-analytical studies discussed previously have suggested that some tests provide more valid and reliable measurements of identifiable dimensions of hand skill. No attempt was made to measure all potentially significant factors of hand proficiency in this study. Four recurring dimensions were

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5 A copy is also found in Appendix 1.

selected and deemed sufficient for the purpose of a preliminary investigation.

The first factor chosen was dexterity, or fine manipulative skills, to be measured by the grooved peg board task.[6,7] The second was arm-movement steadiness to be measured by the maze coordination or maze movement steadiness test.[8] Thirdly, a finger-tapping task was selected to determine finger tapping speed.[9] Finally, as strength[10] has been consistently deemed a relevant dimension of hand skill, a hand dynamometer task was included to measure this factor.

The four tasks selected have been widely used in motor skills research. A summary description of each follows.

(a) Grooved Peg Board.- The subject, working as quickly as he can, places grooved pegs in a board with holes similarly grooved. Kløve[11] and Barnsley[12] have reported

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6 E. A. Fleishman and W. E. Hempel, "A Factor Analysis of Dexterity Tests," in Personnel Psychology, Vol. 7, No. 1, 1954, p. 27-29.

7 R. H. Barnsley, Handedness and Related Behavior, unpublished doctoral dissertation presented to the Department of Psychology, McGill University, Quebec, 1971, p. 45.

8 R. H. Barnsley and M. S. Rabinovitch, "Handedness: Proficiency Versus Stated Preference," in Perceptual and Motor Skills, Vol. 30, 1970, p. 353-354.

9 Ibid., p. 355-356.

10 Barnsley, op. cit., p. 51.

11 H. Kløve, Motor Steadiness Battery, Madison, Department of Neurology, Medical Center, University of Wisconsin, no date; reported in Barnsley and Rabinovitch, op. cit., p. 345.

12 Barnsley, op. cit., p. 33-39.

reliability estimates of .78 and .79 for the time to complete this task.

(b) Maze Coordination Test (or Maze Movement Steadiness Test).- Using a stylus, each subject traces a track through the maze attempting not to make contact with the walls. No time limit is set on each trial. A counter records the number of contacts, while a timer records the amount of time in hundredths of a second spent in contact. Reliability estimates of .84 and .85 have been reported by Kløve[13] for time spent in contact and number of touches, respectively. Barnsley[14] recently obtained significantly lower test-retest reliabilities of .44 and .59 on the same measures.

(c) Finger Tapping Speed.- The subject taps a mechanical tapper with his index finger as fast as he can for ten seconds. Reliability estimates of .88 and .91 for the number of taps were reported by Kløve[15] and Barnsley,[16] respectively.

(d) Hand Dynamometer.- Each subject holds a Smedley hand dynamometer in one hand, points it toward the floor and squeezes as hard as he can. Strength measures are recorded in kilograms, precise to .5 kilogram. Barnsley[17] and

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13 Kløve, op. cit., reported in Barnsley and Rabinovitch, op. cit., p. 348.

14 Barnsley, op. cit., p. 33-39.

15 Kløve, op. cit., reported in Barnsley and Rabinovitch, op. cit., p. 348.

16 Barnsley, op. cit., p. 33-39.

17 Ibid.

Burge[18] are two previous investigators who have reported high reliability estimates of .95 and .94 for this test.

Clinical experience at the Neuropsychology Laboratory of the Royal Ottawa Hospital also suggests a relationship between performance on these tasks and the functioning of different areas of the brain. Deficient performance on the peg board task seems frequently associated with temporal lobe lesions. Similar associations have been observed between performance on the maze steadiness task and cerebellar functioning, between finger tapping performance and the frontal lobe and between hand dynamometer proficiency and both temporal lobe and motor strip areas of the brain.

2. The Sample

Sixty-four subjects from two third-year undergraduate classes in Personality Psychology volunteered to participate in the project and completed the first administration of the Physical Data Questionnaire. Of this group, fifty-one were females and thirteen were males. All subjects were invited to participate in the motor testing at a later date. Forty-three females and three males did so. Considering that

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18 I.C. Burge, "Some Aspects of Handedness in Primary School Children," in British Journal of Educational Psychology, Vol. 22, 1952, p. 45-46.

differences were reported in chapter 1 between the preference, relative skill and preferred hand skill distributions of males and females, and that the influence of the sex variable could not be investigated with the available sample, this writer analyzed and tabulated the results of the female participants only.

The subjects ranged widely in age from nineteen years 4 months, to forty years 3 months, with a mean of twenty-eight years 5 months.

In order to encourage participation and ensure adequate motivation, the subjects were promised a five dollar stipend to be paid upon completion of all testing.

3. Method of the Experiment

A. Assessment of Hand Preference

The Physical Data Questionnaire was administered at the end of two regular classroom periods to the sample of undergraduate students in personality psychology described previously.

The scoring of the questionnaire proceeded as follows. Responses to all items other than the eleven items of the handedness questionnaire were disregarded. To each of the latter questions, three responses were possible: right, left, or either. Right responses to each of the six primary questions were weighted 2 and to each of the five secondary questions were weighted 1. Weights of 2 and 1 were also given for Left answers to primary and secondary questions, respectively. A Right Total and Left Total were computed separately for each subject. The highest obtainable Right or Left total was 17. No weight was given to an Either score.

In order to obtain an estimate of an individual's degree of hand preference on a continuous scale, a hand preference index was computed from the following formula: (R-L)/(R+L). This yielded a score for each subject which reflected the degree and direction of hand preference on a scale from -1.00 to +1.00 where a negative score indicated an excess of left- over right-handedness and a positive score, the opposite. A score of -1.00 indicated a left-hander consistent in preference for the use of the left hand and a score of +1.00 a right-hander consistent in preference for the use of the right hand. A score of zero indicated maximal inconsistency in hand preference. As scores increased from zero to unity, either positive or negative, they reflected increasing consistency in hand preference for the left and right hands, respectively. The algebraic sign of the index indicated at a glance which hand is the preferred for any given individual.

B. Assessment of Hand Proficiency

During the regular class periods immediately following that during which the hand preference questionnaire was first administered, those volunteers who had completed the Physical Data Questionnaire were asked to participate in the second phase of the experiment. This part consisted of an individual testing session of approximately twenty minutes duration. Two full days, from the hours of 9:00 a.m. to 10:00 p.m., were divided into twenty-minute individual testing periods. Subjects were requested to register for a time convenient to them. Forty-six subjects did so.

Testing was held in an office provided by the director of the service courses in psychology at the University of Ottawa. It was situated on the main campus of the university and of easy access. Of the forty-six subjects who had registered for the second phase of the experiment, thirty-five came at the pre-arranged time, only three of whom were males. Since fewer subjects participated than was anticipated, a third testing session was scheduled for the following week and an effort was made to contact all female subjects who had completed the handedness questionnaire and who had either been absent at the subsequent class period when registration for the motor testing was done or had registered and failed to come at the agreed time. Thus, eleven additional female completed the motor testing, increasing the total of female subjects to forty-three.

The skill tests were administered individually by this investigator to each of the experimental subjects during one of the pre-arranged testing periods, all within ten days of the administration of the handedness questionnaire. Instructions for each of the motor tests were a slightly modified version of those used at the Neuropsychology Laboratory of the Royal Ottawa Hospital. A careful attempt was made to respect them in the administration of the tests. Details of these instructions will be found in Appendix 2. Due to a procedural error, one subject's scores on the grooved peg board task were eliminated from all analyses.

The motor tests were administered in the following order to all subjects: the maze coordination task, the hand dynamometer task, the grooved peg board test, and the finger tapping speed task. The average time of administration was twenty minutes. Two trials with each hand were required in the maze coordination and hand dynamometer tasks, while one trial per hand was given on the grooved peg board test. A minimum of three trials with both the right and left index fingers was provided on the finger tapping speed task. If the three scores obtained by one finger were within a range of five of one another, no further trials were required.

Otherwise, additional trials were administered to a maximum of ten until three of the scores fell within a range of five.

To minimize the potential influence of order of test administration, alternate subjects began with their preferred and non-preferred hands, respectively, as determined by their index of hand preference. When two or more trials were required with each hand, the hands were alternated with each trial.

Each motor test yielded three main scores for each subject: the preferred hand score or P score, the non-preferred hand score or NP score, and the difference score or P-NP score reflecting the level of differential hand skill. P and NP hand performance was assessed differently on the various skill measures. The maze coordination task yielded both timer and counter scores for each hand defined as the cumulative score resulting from both trials. The hand dynamometer preferred and non-preferred hand scores were the average of P and NP scores on each of two trials. A third trial with each hand was administered at the end of the testing session when a spread of more than three kilograms was obtained between trials one and two. The time to complete the task with each hand represented the P and NP scores on the grooved peg board measure. The finger tapping speed P and NP scores were the average of the first three trials with each hand which produced scores falling within a range of five. Difference scores for each subject were computed on each task by subtracting the NP from the P scores.

Two indices of an individual's overall level of hand skill were computed from the P, NP and P-NP scores described above. The first is the hand specialization index and was calculated as follows: on each task, all values of the P-NP distribution were transformed into z-score deviation units or standard scores. When appropriate, the z-scores were operationally multiplied by -1 so that positive values always reflected superior P over NP performance. The standard scores were then transformed into Z-scores using the equation $Z = 10z + 50$. Each individual's specialization index was obtained by averaging the P-NP Z-scores computed from his performance on each skill test.

A Preferred Hand Motor Index (P Hand Index) was similarly computed: the preferred hand scores on each task were transformed into z-score deviation units, operationally multiplied by -1 when appropriate, so that positive values always indicated superior performance, and then transformed into Z-score values. Each individual's P Hand Index was computed by averaging his P hand Z-scores obtained on all tests.

In chapter 1, some scaling imprecisions inherent in the use of difference scores derived from P and NP scores on motor skill measures were discussed. Computations and statistical procedures involving them were nevertheless carried out in this investigation and are presented in chapter 3 with an awareness of these difficulties. The main focus of this study having been to clarify the relationships between currents methods of assessment of handedness, the development of novel and more precise procedures for this assessment was deemed to be a topic for future research.

C. Reliability and Validity Measurements

In order to obtain an estimate of the test-retest reliability of the hand preference questionnaire, each individual subject was asked to complete anew the Physical Data Questionnaire at the end of the individual motor testing. Scoring procedure and the computation of the hand preference index were identical to that applied to the first administration of the questionnaire.

An alternate measure of hand preference was sought to provide data on the validity of the questionnaire measure. Each subject was asked to perform the actions stipulated in the eleven items of the questionnaire, a procedure previously employed by Hull.[19] This was done during the motor testing session immediately after the administration of the hand dynamometer test. The hand selected to perform each of the activities was recorded. The scoring procedure was identical to that applied to the questionnaire. A Performance Hand Preference Index was computed similarly from the formula (R-L)/(R+L) and yielded an estimate of an individual's degree and direction of hand preference on a continuous scale from -1.00 to +1.00. Using this Performance Hand Preference Index as a valid criterion of hand preference, the value of the questionnaire assessment of hand preference was tested.

No data on the reliability of the hand skill measures were obtained in this study. A second administration of these motor tasks to a sub-sample had been planned for this purpose but could not be carried out.

The validity of a proficiency measurement of handedness was discussed in Chapter I in terms of the following question: is there a central hand skill factor or are the tests measuring task-specific abilities? The degree of relationship between difference scores as well as between P hand scores obtained on each of the motor tasks was investigated in this experiment.

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19 C. J. Hull, "A Study of Laterality Test Items," in Journal of Experimental Education, Vol. 4, 1936, p. 287-290.

D. Selection of Hand Preference Groups

The problem of relating the J-shaped distribution of hand preference and the variety of distributions of hand skill was addressed in Chapter 1. No simple and direct procedure was found. Correlational techniques seemed contra-indicated in this study in view particularly of the lack of adequate measurement of the hand preference variable along its full range from -1.00 to +1.00. (See Figure 1.) A majority of subjects were consistent in hand preference, with only a small number demonstrating any degree of marked inconsistency.

An alternate procedure selected in this study consisted in the formation of several groups varying along the consistency of preference continuum and comparing these on measures of hand skill. This writer decided to pool left- and right-handed subjects into one sample for the following reasons:

1. The small sample of left-handers ruled out independent analysis.
2. Left- and right-handers vary in identical fashion, though in opposite directions along the hand preference continuum.
3. This researcher was unable to find research data comparing the levels of differential and preferred hand skill of consistent left- and right-handers as well as skill levels of inconsistent left- and right-handers. There is some evidence

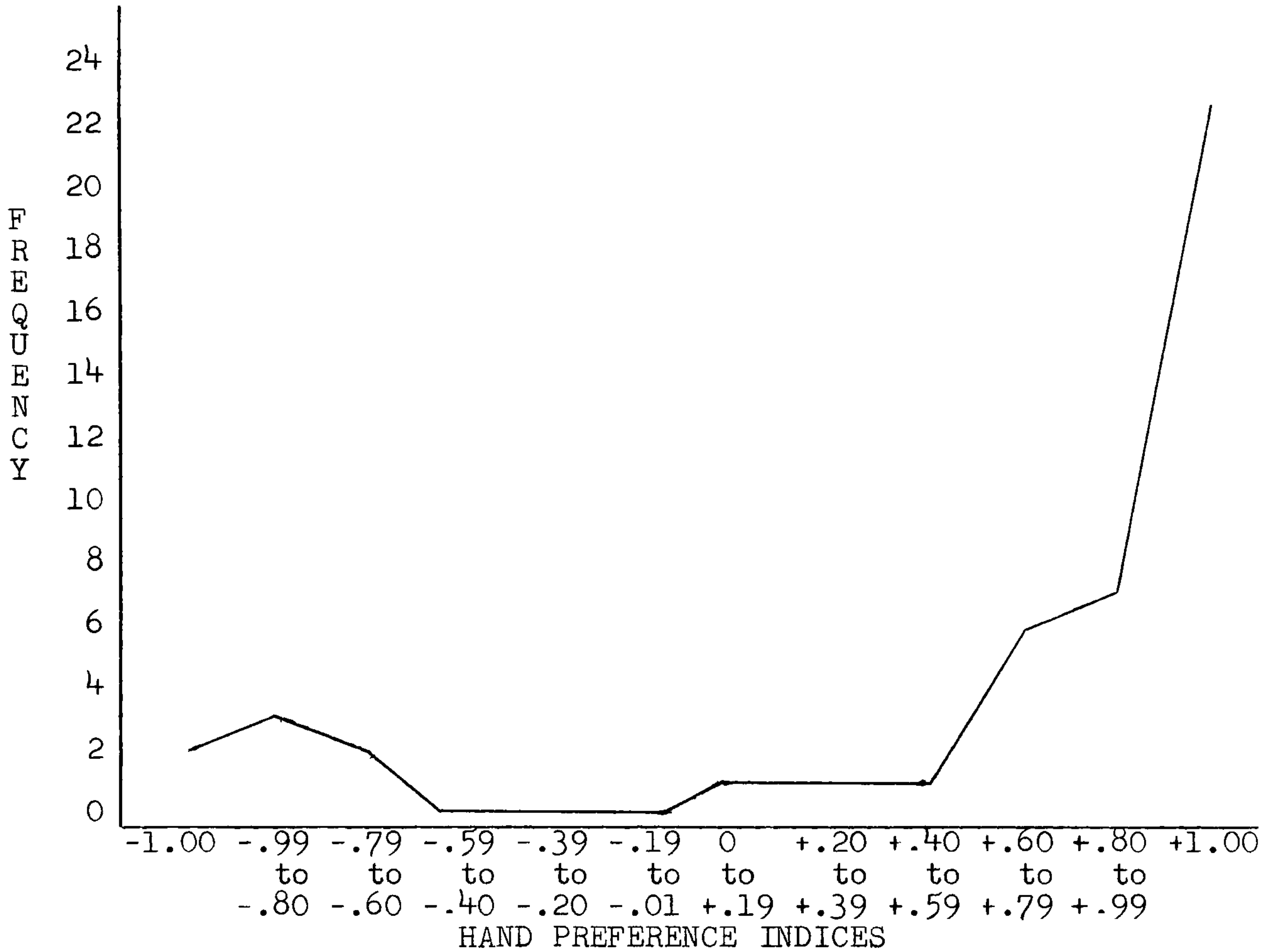

Figure 1.- Frequency Polygon Representing the Distribution of Hand Preference Indices Obtained by a Sample of Forty-three Female Undergraduate Students.

to suggest that the distribution of relative skill is normal[20,20a] and that consistent right- and left-handers obtain higher mean skill difference scores, albeit at different ends of the R-L continuum, than do inconsistent right- and left-handers who on the average obtain smaller difference scores. Thus, it seems reasonable to suggest that consistent handers, both left and right, are somewhat comparable at a differential skill level.

4. Mean hand specialization indices obtained by consistent right-handers, consistent left-handers and a pooling of both groups were compared by inspection. Similarly, mean hand specialization indices obtained by inconsistent right-handers, inconsistent left-handers and a pooling of these groups were compared. Identical comparisons were then extended to the mean P hand indices obtained by consistent and inconsistent handers given the total sample, right-handers only and left-handers only. In all comparisons, the total sample means were very similar to those obtained by the right-handed subsample.

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20 M. Annett, "The Growth of Manual Preference and Speed," in British Journal of Psychology, Vol. 61, No. 4, 1970b, p. 550.

20a T.L. Woo and K. Pearson, "Dextrality and Sinistrality of Hand and Eye," in Biometrika, Vol. 19, 1927, p.165-199.

5. The distributions of scores of left- and right-handed subjects on the skill measures were examined to assess whether differences in the pattern of scores of these groups were evident. Only on the dynamometer task were left-handers somewhat "exceptional": three of seven subjects obtained higher right-hand strength scores while for right-handers, only one of thirty-six demonstrated superior left-hand grip strength. Overall, the dispersion of scores obtained by right- and left-handers seemed very similar.
For these reasons, the potentially confounding influence of the few left-handers was deemed negligible and the samples pooled.

The questionnaire index of hand preference was employed to ascribe all subjects to one of three groups varying in degree of consistency of hand preference. Group 1 contained all consistent handers, i.e., all subjects who obtained a preference index of -1.00 or +1.00; twenty-three subjects were in this group. Group 2 was composed of all subjects who displayed only moderate inconsistency in hand preference, i.e., who obtained hand preference indices ranging from +.80 to +1.00 and from -.80 to -1.00; seven students were in this group. Group 3 contained all thirteen inconsistent handers whose hand preference indices ranged from -.80 to +.80.

The three hand preference groups were labeled consistent handers, moderately inconsistent handers, and inconsistent handers, respectively.

4. Restatement of Specific Hypotheses.

The specific hypotheses which were put to the test are presented here in null form.

1. There will be no greater than chance association between the preferred hand and most proficient hand on each of five measures of hand skill and as determined by the P and NP composite scores.

2. There will be no significant differences between consistent and inconsistent handedness groups in terms of the frequency of agreement between the preferred and most proficient hands on each of five manual skill measures and as determined by the P and NP composite scores

3. There will be no significant differences between P-NP scores obtained by groups of consistent, moderately inconsistent, and inconsistent handers on each of five hand skill measures and between the hand specialization indices computed for subjects within these three groups.

4. There will be no significant differences between P scores obtained by groups of consistent, moderately inconsistent, and inconsistent handers on each of five hand skill measures and between P hand proficiency indices computed for subjects within these three groups.

5. There will be no significant relationship between difference scores and P hand scores obtained on five measures of hand skill as well as between hand specialization and P hand indices.

5. Statistical Operations

This section presents the statistical operations which were selected and employed in testing the stated hypotheses with the data of the experiment.

Pearson product-moment coefficients of correlation were computed to obtain both a test-retest reliability estimate of the hand preference questionnaire, and an estimate of questionnaire criterion-related validity as tested against the performance hand preference measure.

To obtain validity estimates for the hand skill measures in terms of the consistency of what is measured by all tasks, Pearson product-moment coefficients of correlation were computed between all sets of difference scores, including the hand specialization indices, taken in pairs, and all sets of preferred hand scores, including the P hand motor indices, taken in pairs. Difference scores on the maze timer, maze counter, and grooved peg board were operationally multiplied by -1 in these analyses such that positive scores indicate superior preferred hand performance.

To test hypothesis 1, a chi-square analysis was performed for each of the five hand skill measures to determine whether the frequency of agreement between the P hand and the most proficient hand was significantly greater than chance expectations. In order to assess the relation of the preferred hand to an estimate of the most skillful hand derived from all proficiency measures, the P and NP scores were grouped into one sample on each task, raw scores transformed into standard scores, and these operationally multiplied by -1 when appropriate, such that a positive score always reflected superior performance on each task. P and NP standard scores were then summed and averaged separately for each subject to yield indices of his level of P and NP hand skill across all tasks. These were labeled P and NP composite scores. The most skillful hand over all tasks was that which obtained the highest positive composite score value. The frequencies of agreement and non-agreement between preferred and this most skillful hand were then compared in a 2 X 2 contingency table. The chi-squared test was applied using Yates' correction for continuity[21] to minimize the effect of the small expected frequencies. In view of the latter and the relatively small sample size, the more conservative .01 level criterion for significance was selected.

A 2 X 2 chi-square analysis was also performed for each of five manual skill measures as well as for the P and NP composite scores comparing groups of consistent and inconsistent handers in terms of the frequency of agreement

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21 A.E. Maxwell, Analyzing Quantitative Data, London, Methuen, 1961, p. 21-23.

and non-agreement between preferred and most proficient hands (Hypothesis 2). Yates' correction for continuity was again used for the reason given above and the .01 level criterion for significance selected.

To test for significance of the differences in hand skill scores (Hypothesis 3) observed between the three hand preference groups, several one-way analyses of variance or <u>Anovas</u> were conducted. More specifically, F tests of significance were performed between the P-NP or difference scores on all motor measures and between the hand specialization indices obtained by the three hand preference groups. Similarly, F tests compared the P hand or preferred hand scores (Hypothesis 4) on all motor measures and the P hand proficiency indices obtained by the three hand preference groups. The formula for the F ratio was

$$F = \frac{\text{Mean Squares Between}}{\text{Mean Squares Within}}$$

where the critical value is ${}_{.95}F_{(k-1,\ N-3)}$.

In view of the very unequal n's in the hand preference groups, and the relatively small sample sizes, it was deemed important to verify whether the data satisfied the homogeneity of variance assumption for <u>Anova</u>. Hartley's F-max test was susceptible to use with unequal n's[22] and selected in this

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22 R.E. Kirk, <u>Experimental Design: Procedures for the Behavioral Sciences</u>, Belmont, Brooks/Cole, 1968, p. 62.

study. The variances of the three hand preference groups were thus compared on each of the hand skill variables. The statistic employed was

$$Fmax = \frac{s_1^2 \text{ largest}}{s_2^2 \text{ smallest}}$$

which is the ratio of the largest over the smallest group variance and the critical value for which is $_{.99}Fmax_{(k,\ n-1)}$ determined using the Fmax tables. In this occurrence of unequal group sizes, the value of n is the number of subjects in the largest group.

A stringent significance criterion (.01 level for alpha) was selected for the following reasons: (1) When n's are unequal, the use of the largest n to determine the degrees of freedom results in the rejection of the null hypothesis more often than should be the case.[23,24] The large differences in group sizes in this study seemed to warrant a more conservative test. (2) Games, Winkler and Probert,[25] in a recent study, found the Fmax test to be a particularly powerful

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23 *Ibid*., p. 62

24 B.J. Winer, *Statistical Principles in Experimental Design*, New York, McGraw-Hill, 1962, p. 94.

25 P.A. Games, H.B. Winkler, and D.A. Probert, "Robust Tests for Homogeneity of Variance," in *Educational and Psychological Measurement*, Vol. 32, No. 4, 1972, p. 894.

test which runs an inflated risk of rejection of the null hypothesis.

The Newman-Keuls studentized range statistic[26] was employed when a F ratio was significant to identify where the significant difference or differences actually occurred. In this procedure, the level of alpha error is controlled for each contrast independently and thus permitted a powerful test. This quality was particularly important in view of the relatively small N. The formula of this statistic is

$$q_r = \frac{M_1 - M_2}{\sqrt{MS_e/n}}$$

where M_1 and M_2 are the means being compared, MS_e the error variance and n the harmonic mean of sample sizes when these are unequal.[27] The critical value of the test is $_{.95}\,q_r\,(r,\ fe)$. The range or number of steps between the two compared means is r and fe represents the degrees of freedom of the error variance.

Identification of significant differences between the motor scores obtained by the various hand preference groups indicated that some association existed between the consistency

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26 B.J. Winer, Statistical Principles in Experimental Design (2nd ed.), New York, McGraw-Hill, 1971, p. 192.

27 Ibid., p. 191.

of hand preference and hand skill measures of handedness. However, the F and q_r statistics told us nothing about the strength of association between these two variables. An estimate of the degree of association, linear or non-linear, between the preference and proficiency variables was obtained by computing ω^2 (Greek Omega Squared).[28] The value of ω^2 represents the proportion of variance in the motor scores accounted for by variance in the hand preference scores. The higher the value of ω^2 the greater the ability of hand preference scores to predict accurately hand skill scores. A reasonable estimate of the value of ω^2 was given by

$$\text{est } \omega^2 = \frac{\text{SS Between} - (k-1)\text{ MS Within}}{\text{SS Total} + \text{MS Within}}$$ [29]

where SS stands for the Sum of Squares, MS the Mean Squares, and k the number of groups.

Estimates of the power of the F tests performed, or of their ability to identify significant differences when in fact significant differences exist, were obtained using the following formulae and appropriate power tables:[30]

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28 W.L. Hays, Statistics, New York, Holt, 1963, p. 325.

29 Ibid., p. 382.

30 J. Cohen, Statistical Power Analysis for the Behavioral Sciences, New York, Academic Press, 1969, p. 266-397.

$$f = \frac{\sigma_m}{\sigma}$$

where σ_m is the standard deviation of the population means and σ the standard deviation of the population. The value of σ_m was computed as follows since groups were of unequal size:

$$\sigma_m = \sqrt{\frac{\sum_{i=1}^{k} n_i \ (m_i - m)^2}{N}}$$

where m_i was the population means, m was the grand mean of the combined population, n_i was n in each group, and k the number of groups.

The other elements needed for use of the statistical power tables were as follows: the degrees of freedom of the numerator of the F ratio (k-1); the significance criterion or the level of alpha error; the average sample size n where $n = \frac{N}{k}$.

In order to test hypothesis 5 regarding the relationship between levels of preferred hand skill and differential skill, "extreme" groups on the hand specialization dimension were formed. Subjects were ranked according to the size of their hand specialization index. Group 1 was composed of those 15 subjects who ranked highest and group 2 was composed of those 15 subjects who ranked lowest. The mean hand specialization indices of groups 1 and 2 were respectively 56.8 and 43.9. The t statistic was then applied to test for differences between the mean P hand scores obtained by "high" and "low" groups on each hand skill measure. Similar comparisons were made for NP hand scores. When significant differences obtained, the degree of association between the differential skill and P or NP skill variables was estimated using the following formula:

$$\text{est } \omega^2 = \frac{t^2 - 1}{t^2+N_1+N_2-1}$$ [31]

Finally, to investigate the influence of order of administration of the motor skill tests to the preferred and non-preferred hands, respectively, several one-way Anovas for order effects were conducted comparing the P, NP and P-NP scores obtained on each of the skill measures by those subjects who began the tests with their preferred and those who began the tests with their non-preferred hands. The formula employed was the F ratio given above with critical value ${}_{.95}F_{(k-1,\, N-2)}$.

This chapter has presented the design of one experiment to test the general hypotheses stated at the conclusion of Chapter I. In Chapter III, the results of the experiment are presented and discussed.

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31 Hays, op. cit., p. 327.

CHAPTER III

PRESENTATION AND DISCUSSION OF RESULTS

The results of the experiment will be presented in the first section, according to their contribution to the five headings listed below:

A. Psychometric Qualities of the Questionnaire and Skill Measures;
B. Hypotheses 1 and 2;
C. Hypotheses 3 and 4;
D. Hypothesis 5; and
E. Experimental Order Effects.

Section two will discuss and interpret these findings.

1. Results of the Experiment.

A. Psychometric Qualities of the Questionnaire and Skill Measures

An estimate of criterion-related validity of Annett's hand preference questionnaire was obtained by correlating the indices of hand preference obtained on the first administration of the questionnaire with preference indices computed from the actual performance of the activities listed in the questionnaire. A Pearson product-moment coefficient of correlation of .99 was obtained. The identical correlational technique was applied to the sets of indices of hand preference obtained from the first and second administrations of the handedness questionnaire. A test-retest reliability coefficient of .96 was found.

The validity of the hand skill measures was considered in terms of the consistency of what is measured by each of them. Intertask correlations between obtained difference scores were generally low in absolute value. The high correlation between maze timer and maze counter difference scores was not unexpected since their measurements were interdependent. Correlation coefficients between individual tasks and the hand specialization indices were within the moderate to high range, varying from .37 to .83. All correlations are presented in Table I.

Intertask correlations between obtained preferred hand scores were similar in range but slightly inferior in absolute value to those reported for the difference scores. The elevated correlation ($r = .93$) between the maze counter and maze timer scores took exception for the reason given above. Correlations between the individual skill measures and the preferred hand indices ranged from .38 to .79 in absolute value (Table II). They were slightly lower, overall, than those reported above for the difference scores.

Table I.-

Presentation of Pearson Product-Moment Coefficients of Correlation Computed between All Sets of Difference Scores, Including the Hand Specialization Indices, Obtained on Five Hand Skill Measures by a Sample of 43 Female Undergraduate Students.

Hand Skill Measure	Maze Counter	Hand Dynamometer	Grooved Peg Board[a]	Finger Tapping	Hand Specialization Indices
Maze Timer	.88**	.09	.20	.22	.83**
Maze Counter		-.07	.28	.11	.75**
Hand Dynamometer			-.09	.13	.37*
Grooved Peg Board				-.06	.44**
Finger Tapping					.47**

a All correlations involving difference scores on the peg board task included only 42 subjects.

** $p<.01$

* $p<.05$

Table II.-

Presentation of Pearson Product-Moment Coefficients of Correlation Computed Between All Sets of Preferred Hand Scores, Including the Preferred Hand Skill Indices, Obtained on Five Hand Skill Measures by a Sample of 43 Female Undergraduate Students.

Hand Skill Measure	Maze Counter	Hand Dynamometer	Grooved Peg Board[a]	Finger Tapping	Preferred Hand Indices
Maze Timer	.93**	-.17	-.04	-.09	-.79**
Maze Counter		-.07	-.01	-.06	-.75**
Hand Dynamometer			.22	.01	.42**
Grooved Peg Board				.002	-.38*
Finger Tapping					.43**

a All correlations involving preferred hand scores on the peg board task included only 42 subjects.

** $p < .01$

* $p < .05$

B. Hypotheses 1 and 2

Results of a first series of chi-square analyses reported in Table III showed that observed frequencies of agreement and non-agreement between the preferred and most proficient hands were significantly different from chance expectations on four of five hand skill measures as well as on composite P and NP hand scores. On the maze coordination timer measure, observed differences, though beyond the .05 level, failed to attain the selected .01 level criterion for significance. A high degree of association between preferred and most skillful hand is suggested by these data. Overall proportions of agreement between the P and most skillful hands ranged from .77 on the peg board to .93 on the finger tapping speed tasks. Accuracy of prediction from the P to most proficient hands increased to 95% when composite scores for P and NP hand performance across all five measures were employed. Hypothesis 1 which stated that there will be no greater than chance association between the preferred and most proficient hands on five measures of hand skill was rejected.

Subsequent chi-square analyses comparing consistent and inconsistent handers in terms of the frequencies of agreement and non-agreement between the P and most proficient hand were not statistically significant (Table IV). A possible bias was introduced in these results because the relative proportions of right- and left-handers were different for the consistent and inconsistent handedness groups. To ascertain the influence of the potential bias, right- and left-handers were compared in terms of the frequency of agreement and non-agreement between their preferred and most skillful hands. Chi-square values were non-significant except on the hand dynamometer test where differences beyond the .01 level were found. As a result, the chi-square value reported for this latter measure in table IV may have been somewhat artifactual. A separate test of the contingency carried out for the right-handed sample was non-significant. The small number of left-handers precluded such an analysis.

On the basis of these findings, null hypothesis 2 was not rejected. No marked degree of association between two levels of consistency in hand preference and frequencies of agreement between the P and most proficient hands was suggested by these data.

Table III.-

Summary of Chi-Square Analyses for 2 X 2 Contingency Tables Testing Whether Observed Frequencies of Agreement and Non-Agreement between the Preferred and Most Proficient Hands on Each of Five Hand Skill Measures as well as on Composite P and NP Hand Scores Were Significantly Different from Chance Expectations for a Sample of 43 Female Undergraduate Students.[a]

Hand Skill Measure	N	$\frac{f_{agree}}{N}$	f_o Agree		N-Agree		χ^2	Level of Prob.[b]
			R	L	R	L		
Maze Timer	42	.81	30	4	5	3	4.07	$p < .05$
Maze Counter	41	.88	30	6	4	1	13.44	$p < .001$
Hand Dynamometer	43	.91	35	4	1	3	11.98	$p < .001$
Grooved Peg Board	42	.77	25	7	10	0	9.57	$p < .01$
Finger Tapping	41	.93	33	5	1	2	16.66	$p < .001$
P and NP Composite Scores	43	.95	34	7	2	0	26.14	$p < .001$

a Subjects who demonstrated equal P and NP hand performance on any one measure were not included in the data analysis for that measure.

b Critical values: $.99\chi^2$ (d.f. = 1) = 6.64
$.999\chi^2$ (d.f. = 1) = 10.83

Table IV.-

Summary of Chi-Square Analyses Testing Whether Observed Frequencies of Agreement and Non-Agreement between Preferred and Most Proficient Hands on Each of Five Hand Skill Measures as well as on P and NP Composite Scores were Significantly Different for Consistent and Inconsistent Handedness Groups.[a]

Hand Skill Measure	Consistent			Inconsistent			χ^2	Level of Prob.[b]
	f_{agree}	$f_{n\text{-}agree}$	$\frac{f_{agree}}{N}$	f_{agree}	$f_{n\text{-}agree}$	$\frac{f_{agree}}{N}$		
Maze Timer	21	2	.91	7	6	.54	4.75	NS
Maze Counter	20	2	.91	10	3	.77	0.41	NS
Hand Dynamometer	22	1	.96	10	3	.77	1.36	NS
Grooved Peg Board	17	5	.77	10	3	.77	0.15	NS
Finger Tapping	21	1	.95	11	2	.85	0.23	NS
P and NP Composite Scores	23	0	1.00	18	2	.89	0.68	NS

a Subjects who demonstrated equal P and NP hand performance on any one skill measure were not included in the data analysis for that measure.

b Critical value: $_{.99}\chi^2$ (d.f. = 1) = 6.64

C. Hypotheses 3 and 4

These hypotheses dealt with the significance of differences obtained by three hand preference groups on five skill measures as well as on the over-all skill indices. The selection of the analysis of variance or Anova procedure led to the testing of its homogeneity of variance assumption. The results of Hartley's F-max tests comparing the variances of P-NP and P scores obtained on all five skill measures are reported in Tables V and VI, respectively. The homogeneity of variance assumption was sustained for P-NP and P scores and the Anovas between the scores were proceeded with.

The F statistic was used initially to compare difference scores obtained by the three handedness groups. The comparison of hand specialization indices was significant beyond the .025 level of probability, while scores on the maze coordination timer differed significantly beyond the .05 criterion. A third comparison involving the hand dynamometer scores was significant beyond the .06 level. These provided partial support for the rejection of null hypothesis 3 and will be retained for further analysis. Results of all comparisons are found in Table VII.

The preferred hand scores were compared similarly. None of the F tests reported in Table VIII were significant beyond any acceptable criterion level. Null hypothesis 4 was not rejected on the basis of these data.

Table V.-

Summary of the Fmax Tests for Homogeneity of Variance between Difference Scores Obtained on Each of Five Hand Skill Measures by Consistent, Moderately Inconsistent, and Inconsistent Hand Preference Groups (N=43).

Hand Skill Measure	Variance			Fmax	Level of Prob.
	Consistent Handers (n=23)	Moderately Inconsistent Handers (n=7)	Inconsistent Handers (n=13)		
Maze Timer	4898.58	5464.29	1971.54	2.77	NS
Maze Counter	41.01	22.86	19.72	2.08	NS
Hand Dynamometer	7.15	8.28	9.11	1.27	NS
Grooved Peg Board	38.60[a]	62.34	72.70	1.88	NS
Finger Tapping	14.41	13.41	20.88	1.56	NS

a n is 22 on this measure.

Table VI.-

Summary of the Fmax Tests for Homogeneity of Variance between Preferred Hand Scores Obtained on Each of Five Hand Skill Measures by Consistent, Moderately Inconsistent, and Inconsistent Hand Preference Groups (N=43).

Hand Skill Measure	Variance			Fmax	Level of Prob.
	Consistent Handers (n=23)	Moderately Inconsistent Handers (n=7)	Inconsistent Handers (n=13)		
Maze Timer	972.69	607.35	1701.25	2.80	NS
Maze Counter	9.41	6.51	19.91	3.03	NS
Hand Dynamometer	24.19	17.35	19.85	1.39	NS
Grooved Peg Board	41.44[a]	53.92	68.89	1.30	NS
Finger Tapping	60.18	29.39	38.14	2.05	NS

a n is 22 on this measure.

Table VII.-

Presentation of Means and F Ratios as Summary of the Analyses of Variance between Difference Scores and Hand Specialization Indices Obtained by Groups of Consistent, Moderately Inconsistent, and Inconsistent Handers on Five Hand Skill Measures (N=43).

Hand Skill Measure	Mean Scores (P - NP)			Degrees of Freedom	F Ratio	Level of Prob.
	Consistent Handers (n=23)	Moderately Inconsistent Handers (n=7)	Inconsistent Handers (n=13)			
Maze Timer[a]	-72.17	-66.29	-13.23	2,40	3.31	$p < .05$
Maze Counter[b]	-5.82	-5.00	-2.23	2,40	1.60	NS
Hand Dynamometer[c]	4.24	4.11	1.80	2,40	3.09	$p < .06$
Grooved Peg Board[d]	-6.90	-6.64	-4.62	2,39	0.39	NS
Finger Tapping[b]	4.53	4.90	4.54	2,40	0.02	NS
Hand Specialization Indices[e]	52.54	51.21	46.73	2,40	4.23	$p < .025$

a Results given in hundredths of a second.
b Results given in frequency units.
c Results given in kilograms.
d Results given in seconds.
e Results given in Z score units.

Table VIII.-

Presentation of Means and F Ratios as Summary of the Analyses of Variance between Preferred Hand Scores and Preferred Hand Skill Indices Obtained by Groups of Consistent, Moderately Inconsistent, and Inconsistent Handers on Five Hand Skill Measures (N=43).

Hand Skill Measure	Mean Scores (P Hand)			Degrees of Freedom	F Ratio	Level of Prob.
	Consistent Handers (n=23)	Moderately Inconsistent Handers (n=7)	Inconsistent Handers (n=13)			
Maze Timer[a]	35.09	45.29	51.77	2,40	0.99	NS
Maze Counter[b]	3.74	5.00	4.69	2,40	0.48	NS
Hand Dynamometer[c]	33.11	29.57	29.66	2,40	2.75	NS
Grooved Peg Board[d]	55.78	56.29	57.89	2,39	0.33	NS
Finger Tapping[b]	43.34	48.62	44.64	2,40	1.44	NS
P Hand Indices[e]	51.26	49.78	47.96	2,40	1.58	NS

a Results given in hundredths of a second.
b Results given in units of frequency.
c Results given in kilograms.
d Results given in seconds.
e Results given in Z score units.

The Newman-Keuls studentized range statistic was applied to those comparisons which had yielded significant F ratios in order to determine which groups actually evidenced significant differences. The P-NP group means obtained on the maze coordination timer measure were considered first (Table IX). Differences beyond the .05 level of probability were found between the consistent handers and inconsistent handers groups. Similar differences beyond the .05 level were obtained between groups of moderately inconsistent and inconsistent handers.

The mean hand specialization indices of the three hand preference groups were similarly compared (Table X). The Newman-Keuls test revealed mean differences between the inconsistent handers and both the moderately inconsistent and the consistent handers groups. These differences were, in both cases, statistically significant beyond the .05 level of probability.

The difference scores obtained on the hand dynamometer task were also subjected to further analysis although the *Anova* F ratio was slightly inferior to that required by the .05 criterion level. A statistically significant difference was found between the mean difference scores of moderately inconsistent and inconsistent handers on this hand strength task. Differences between the consistent and

Table IX.-

Summary of Post Hoc Comparisons Involving the Newman-Keuls Studentized Range Statistic between All Pairs of Means Obtained by Groups of Consistent (Group 1), Moderately Inconsistent (Group 2), and Inconsistent (Group 3) Handers on the Maze Coordination Timer Measure (N-43).

Means Compared	Differences between Means[a]	r^b	$_{.95}q_r(r,40)$	Level of Probability
$M_1 - M_2$	5.888	2	0.348	NS
$M_1 - M_3$	58.943	3	3.486*	$p < .05$
$M_2 - M_3$	53.055	2	3.138*	$p < .05$

a In hundredths of a second.
b r refers to the range between compared means.
* Critical values: $_{.95}q_r(3,40) = 3.44$
$_{.95}q_r(2,40) = 2.86$

Table X.-

Summary of Post Hoc Comparisons Involving the Newman-Keuls Studentized Range Statistic between All Pairs of Means Obtained by Groups of Consistent (Group 1), Moderately Inconsistent (Group 2), and Inconsistent (Group 3) Handers on the Hand Specialization Indices (N=43).

Means Compared	Differences between Means[a]	r[b]	$_{.95}q_{r}(r,40)$	Level of Probability
$M_1 - M_2$	1.332	2	0.920	NS
$M_1 - M_3$	5.808	3	4.012	$p < .05$
$M_2 - M_3$	4.476	2	3.092*	$p < .05$

a In Z score units.
b r refers to the range between compared means.
* Critical values: $_{.95}q_{r}(3,40) = 3.44$
$_{.95}q_{r}(2,40) = 2.86$

inconsistent handers were significant beyond the .06 level (Table XI).

The results of the Anovas and Newman-Keuls tests pointed to the existence of some relationship between various degrees of consistency in hand preference and levels of differential proficiency on several measures of hand skill. The ω^2 (Greek Omega Squared) statistic provided estimates of the strength of association between these variables.

The highest value of ω^2 was .13 obtained from the hand specialization indices. It indicated that 13% of the variance of the hand specialization indices was accounted for by variance in the hand preference indices. All other values of ω^2 associated with P-NP variables were less than .10. The highest ω^2 value associated with P hand skill variables was .075 obtained from the hand dynamometer scores. Values of ω^2 representing the degree of association between the hand preference variable and several manual skill variables are reported in Table XII.

Estimates of the power of the statistical F tests were computed subsequently. These represented the probability of identifying significant differences when in fact they do exist. Estimates reported in Table XIII were generally very low for P-NP as well as P scores, varying from .05 to .61 when the level of alpha error was set at .05. A more liberal alpha criterion increased the range of power estimates from .09 to .73.

Table XI.-

Summary of Post Hoc Comparisons Involving the Newman-Keuls Studentized Range Statistic between All Pairs of Means Obtained by Groups of Consistent (Group 1), Moderately Inconsistent (Group 2), and Inconsistent (Group 3) Handers on the Hand Dynamometer Task (N=43).

Means Compared	Differences between Means[a]	r^b	$_{.95}q_r(r,40)$	Level of Probability
$M_1 - M_2$	0.133	2	0.182	NS
$M_1 - M_3$	2.438	3	3.341	$p<.06$
$M_2 - M_3$	2.305	2	3.159*	$p<.05$

a In kilograms.
b r refers to the range between compared means.
* Critical values: $_{.95}q_r(2,40) = 3.092$
$_{.95}q_r(3,40) = 3.44$

Table XII.-

Presentation of ω^2 (Greek Omega Squared) Indices as Estimates of the Degree of Association between Hand Preference and Four Measures of Hand Skill (N=43).

Hand Skill Measure	F Ratio	Level of Probability	ω^2
Maze Timer P-NP	3.307	$p < .05$	0.097
Hand Dynamometer P-NP	3.091	$p < .06$	0.089
Hand Specialization Indices	4.229	$p < .025$	0.13
Hand Dynamometer P	2.753	$p < .08$	0.075

Table XIII.-

Presentation of the Statistical Power Estimates, Given Three Levels of Alpha Error, for F Tests between Difference Scores, Hand Specialization Indices, Preferred Hand Scores, and Preferred Hand Indices Obtained by Groups of Consistent, Moderately Inconsistent, and Inconsistent Handers on Five Hand Skill Measures (N=43, n=14[a]).

Hand Skill Measure	f Index	Statistical Power Est. for $\alpha=.01$	$\alpha=.05$	$\alpha=.10$
Maze Timer P-NP	0.32	.18	.41	.54
Maze Counter P-NP	0.24	.10	.27	.40
Hand Dynamometer P-NP	0.41	.34	.61	.73
Grooved Peg Board P-NP	0.16	.03	.13	.22
Finger Tapping P-NP	0.04	.01	.05	.09
Specialization Indices	0.26	.10	.27	.40
Maze Timer P	0.17	.05	.14	.25
Maze Counter P	0.17	.05	.14	.25
Hand Dynamometer P	0.35	.24	.49	.63
Grooved Peg Board P	0.35	.24	.49	.63
Finger Tapping P	0.24	.10	.26	.40
P Hand Indices	0.15	.03	.12	.21

a n is the average sample size of the three hand preference groups. It was required in the use of the statistical power tables.

D. Hypothesis 5

Hypothesis 5 dealt with the relation between the proficiency definitions of handedness as the level of P and P-NP hand skill. t values comparing the mean P hand values of groups of subjects with "high" and "low" scores on the hand specialization continuum are reported in table XIV. No mean differences were found to be significant. Null hypothesis 5 was not rejected.

The results of similar analyses involving the NP hand scores are reported in table XV. Mean NP hand differences were found to be significant beyond the .01 level on four skill measures. On the maze timer and counter, the hand dynamometer and NP hand indices, mean scores of the "low" group on the hand specialization continuum were significantly superior to those of the "high" group. Differences between group means on the peg board and finger tapping speed measures were not significantly different from chance expectations. The estimated degree of association between the NP hand scores and the hand specialization continuum was computed where significant differences were found. ω^2 values were .34 and .30 from the maze coordination timer and counter measures, respectively, .26 from the hand dynamometer and .35 from the overall NP hand indices.

Table XIV.-

Presentation of t Ratios Comparing the Mean Preferred Hand Scores, as well as the Preferred Hand Indices, Obtained on Five Hand Skill Measures by Groups of Subjects with High Hand Specialization Indices (Group 1) and Low Hand Specialization Indices (Group 2) (N=30)

Hand Skill Measure	Mean P Hand Scores		t Ratio	Level of Prob.
	Group 1	Group 2		
Maze Timer[a]	39.53	38.4	.09	N.S.
Maze Counter[b]	4.27	3.73	.40	N.S.
Hand Dynamometer[c]	30.04	31.38	.59	N.S.
Peg Board[d]	56.67	57.80	.45	N.S.
Finger Tapping[b]	45.39	47.89	1.24	N.S.
P Hand Indices[e]	50.02	49.37	.32	N.S.

a Results given in hundredths of a second.
b Results given in units of frequency.
c Results given in kilograms.
d Results given in seconds.
e Results given in Z score units.

Table XV.-

Presentation of t Ratios Comparing the Mean Non-Preferred Hand Scores, as well as the Non-Preferred Hand Indices, Obtained on Five Hand Skill Measures by Groups of Subjects with High Hand Specialization Indices (Group 1) and Low Hand Specialization Indices (Group 2). (N=30)

Hand Skill Measure	Mean NP Hand Scores		t Ratio	Level of Prob.
	Group 1	Group 2		
Maze Timer[a]	155.47	44.13	4.03	$p<.001$
Maze Counter[b]	12.67	4.53	3.48	$p<.01$
Hand Dynamometer[c]	25.55	29.75	3.14	$p<.01$
Peg Board[d]	66.27	61.17	1.54	N.S.
Finger Tapping[b]	39.35	40.55	.54	N.S.
NP Hand Indices[e]	45.03	53.86	4.08	$p<.001$

a Results given in hundredths of a second.
b Results given in units of frequency.
c Results given in kilograms.
d Results given in seconds.
e Results given in Z score units.

E. Experimental Order Effects

Results of the Anovas carried out to assess the influence of order of administration of manual proficiency measures on the P, NP, and difference scores are reported in Tables XVI, XVII, and XVIII. Whether the tasks were administered to the P or NP hand initially, affected in a statistically significant manner the results or performances on the grooved peg board and finger tapping speed tests. On the former, difference scores ($p < .03$) and NP hand scores ($p < .05$) were significantly affected, while on the latter P hand scores ($p < .03$) and to a lesser extent the difference scores ($p < .08$) were influenced.

This section has presented the results of this experiment. A discussion and evaluation of the significance of these findings is found in the coming pages.

Table XVI.-

Presentation of Means and F Ratios as Summary of the Analyses of Variance Testing for Order Effects on Preferred Hand Scores Obtained by Two Groups of Subjects Who Performed the Hand Skill Tasks Initially with Their Preferred and Non-Preferred Hands, Respectively.

Hand Skill Measure	Mean Scores (P)		Degrees of Freedom	F Ratio	Level of Prob.
	P Hand Group (n=24)	NP Hand Group (n=19)			
Maze Timer[a]	-45.13	-37.58	1,41	0.49	NS
Maze Counter[b]	-4.63	-3.74	1,41	0.65	NS
Hand Dynamometer[c]	31.49	31.50	1,41	0.00	NS
Grooved Peg Board[d]	-56.50	-56.54	1,40	0.0003	NS
Finger Tapping[b]	42.45	47.30	1,41	5.15	$p<.03$
P Hand Indices[e]	48.96	51.36	1,41	2.11	NS

a Results given in hundreths of a second.
b Results given in frequency units.
c Results given in kilograms.
d Results given in seconds.
e Results given in Z score units.

Table XVII.-

Presentation of Means and F Ratios as Summary of the Analyses of Variance Testing for Order Effects on Non-Preferred Hand Scores Obtained by Two Groups of Subjects Who Performed the Hand Skill Tasks Initially with Their Preferred and Non-Preferred Hands, Respectively.

Hand Skill Measure	Mean Scores (NP) P Hand Group (n=24)	Mean Scores (NP) NP Hand Group (n=19)	Degrees of Freedom	F Ratio	Level of Prob.
Maze Timer[a]	103.87	88.95	1,41	0.51	NS
Maze Counter[b]	9.21	8.32	1,41	0.18	NS
Hand Dynamometer[c]	28.33	27.55	1,41	0.30	NS
Grooved Peg Board[d]	60.42	65.56	1,40	4.44	$p < .05$
Finger Tapping[b]	39.01	41.42	1,41	1.74	NS

a Results given in hundredths of a second.
b Results given in frequency units.
c Results given in kilograms.
d Results given in seconds.

Table XVIII.-

Presentation of Means and F Ratios as Summary of the Analyses of Variance Testing for Order Effects on Difference Scores Obtained by Two Groups of Subjects Who Performed the Hand Skill Tasks Initially with Their Preferred and Non-Preferred Hands, Respectively.

Hand Skill Measure	Mean Scores (P-NP) P Hand Group (n=24)	NP Hand Group (n=19)	Degrees of Freedom	F Ratio	Level of Prob.
Maze Timer[a]	-58.96	-46.37	1,41	0.33	NS
Maze Counter[b]	-4.54	-4.68	1,41	0.006	NS
Hand Dynamometer[c]	3.16	3.89	1,41	0.61	NS
Grooved Peg Board[d]	-3.92	-9.13	1,40	5.60	$p < .03$
Finger Tapping[b]	3.57	5.88	1,41	3.31	$p < .08$
Hand Specialization Indices[e]	49.31	52.15	1,41	2.29	NS

a Results given in hundredths of a second.
b Results given in frequency units.
c Results given in kilograms.
d Results given in seconds.
e Results given in Z score units.

2. Discussion.

The findings will be discussed initially with reference to each of the five specific hypotheses stated in Chapter II. Implications of these findings, potential sources of error, and recommendations for further research will be presented subsequently.

Hypothesis 1.- The first hypothesis investigated the relationship between preferred and most skillful hands. The existence of an over-all strong relation, though not a functional one, between the preferred hand and the most proficient hand was supported by the data of the experiment. The percentage of agreement between them was highest (95%) when composite P and NP hand scores were compared. This supported Ojemann's[1] earlier finding that preferred and most proficient hands agreed more frequently when the latter was predicated on the basis of several hand skill measures. Individual tasks varied considerably in the percentage of P and NP hand agreement. The results on the peg board were notably low as nearly one-fourth of all subjects demonstrated superior NP hand proficiency. Findings suggested it would be hazardous to determine an individual's most proficient hand

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1 R. H. Ojemann, "Studies in Handedness: I. A Technique for Testing Unimanual Handedness," in Journal of Educational Psychology, Vol. 21, No. 8, 1930, p. 610-611.

on the basis of only one measure of hand skill. Barnsley[2] in 1971 reported a 99% level of agreement between the most skillful hand and the preferred hand for writing. In this study, a somewhat lower percentage (88%) obtained given an identical hand preference criterion.

Hypothesis 2.- No significant differences were found between groups of consistent and inconsistent handers in terms of the frequency of agreement between the preferred and most skillful hands. However, the proportions of agreement between the preferred and most skillful hands for the consistent handers were equal on one measure and superior on all others to those obtained by the inconsistent handers. Larger sample sizes in these groups may have uncovered a more significant trend.

Hypothesis 3.- The *Anovas* and *post hoc* analysis pointed to several statistically significant differences between difference scores obtained by the three hand preference groups. On the basis of these differences, null hypothesis 3, which stated that no differences would be found, was partially rejected. All differences were in the direction of higher levels of differential skill for consistent handers and moderately inconsistent handers and

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2 R. H. Barnsley, *Handedness and Related Behavior*, unpublished doctoral dissertation presented to the Department of Psychology, McGill University, Quebec, 1971, p. 67-68.

lower levels for inconsistent handers. No differences were found between the consistent and moderately inconsistent handedness groups, suggesting that this latter group was much more similar at a differential skill level to the consistent than inconsistent handers.

The ordering of means of the preference groups on five of the six skill measures was in the direction of largest skill differences for the consistent handers and smallest for the inconsistent handers, while the moderately inconsistent group tended to obtain intermediate difference scores. Ordering of means on the finger tapping speed task differed from this trend with largest difference scores obtained by moderately inconsistent handers and smallest by the consistent handers. Differences between group means, however, were very small. The fairly consistent ordering of group means suggested that additional significant differences may have been found had larger sample sizes been available.

That statistically significant differences were found between mean levels of differential skill obtained by handers varying in consistency of hand preference led to the estimation of the degree of association between the consistency of preference and differential skill dimensions. It will be remembered that the hand preference data, though analyzed in terms of three discrete levels, represented a continuous distribution of consistency of preference. The largest value of ω^2 was .13 obtained from the overall measure of relative skill, the hand specialization indices. Therefore, though several statistically significant differences were found between difference scores obtained by the hand preference groups, the proportion of common variance between the hand preference and relative hand skill variables was small in all cases. The increase in the ability to predict accurately a subject's level of differential skill, given his degree of consistency in hand preference, was minimal for these data.

Hypothesis 4.- This hypothesis investigated differences in levels of preferred hand proficiency between groups of consistent, moderately inconsistent, and inconsistent handers. No differences between mean skill scores were found to be statistically significant. The data thus failed to support rejection of null hypothesis 4.

A closer examination of the ordering of the means of preferred hand scores obtained by the preference groups failed to yield indications of a trend such as the one underlined for the difference scores. Overall, knowledge of one's degree of consistency of hand preference added little to one's ability to predict preferred hand levels of skill. The highest ω^2 value or proportion of common variance was .075 obtained on the hand dynamometer task. A relationship between these preference and proficiency definitions of handedness was not supported. Although the preferred hand was the most proficient for the majority of subjects, the degree of consistency in hand preference was not a better than chance predictor of the level of preferred hand skill. This performance definition of handedness as the level of preferred hand skill, recently proposed by Barnsley[3] and Barnsley and Rabinovitch,[4] was found in this study to be less highly associated with the hand preference scores than was the performance definition of handedness as the level of skill difference between the hands.

Hypothesis 5.- No evidence was obtained to support a significant relation between the preferred hand scores and the differential skill continuum. Surprisingly enough, the level of NP hand skill, at least on a majority of skill measures, was a much better predictor of the level of differential skill than was the P hand level of skill. Barnsley[5], using correlational techniques, reported a similar finding and questioned on that basis a conceptualization of handedness as the level of skill difference between the hands. He

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3 Barnsley, op. cit., p. 66-74.

4 R.H. Barnsley and M.S. Rabinovitch, "Handedness and 'Automatization' Cognitive Style," in Canadian Journal of Psychology, Vol. 27, No. 1, 1973, p. 7.

5 Barnsley, op. cit., p. 69-70.

viewed handedness as a phenomenon essentially characterized by the development of superior skill in the preferred hand. Both sets of findings suggest tentatively that the level of skill achieved by the non-preferred hand bears a more direct and significant relationship to the degree of differential skill than does the level achieved by the preferred hand. The findings intimate that larger skill differences between the two hands would be mainly accounted for, not by higher levels of skill in the preferred hand, but by the lack of development of high levels of proficiency by the non-preferred hand. Those individuals evidencing small levels of differential skill would tend to be as skillful with their preferred hand and more skillful with their non-preferred hand than individuals demonstrating large skill differences.

These findings do not support Palmer's[6] differentiation hypothesis for handedness where individuals who demonstrate a strongly lateralized pattern of hand skill would have achieved "developmentally more advanced"[7] levels of motor functioning. It is important to note that level of NP hand skill was not significantly associated with levels of

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6 R.D. Palmer, "Development of a Differentiated Handedness", in Psychological Bulletin, Vol. 62, No. 4, 1964, p. 256-272.

7 --------, "Dimensions of Differentiation in Handedness", unpublished paper presented to the Eastern Psychological Association, Boston, 1967, p. 2

differential skill on all skill measures used. Thus the inferences drawn above are tentative and heuristic in purpose.

In summary, the data of this experiment supported a strong predictive relation between the preferred hand and the most skillful hand corroborating earlier findings by Simon[8] and Barnsley,[9] and may be interpreted as providing some empirical support for Provins'[10] hypothesis stressing the developmental interdependence of preferred and most skillful hands. While preferred hand and most proficient hand were related, the degree of consistency in hand preference as determined by a questionnaire measure and the level of preferred hand skill on the proficiency measures were not. Measurements of consistency of preference and proficiency definitions as the level of P hand skill shared little common variance. They seemed to measure rather distinct components of the handedness phenomenon. No previous research data were available on this point.

A similar conclusion was supported with regard to the consistency of preference and level of differential skill definitions of handedness. Most of the variance associated

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8 J.R. Simon, "Steadiness, Handedness and Hand Preference", in <u>Perceptual and Motor Skills</u>, Vol. 18, 1964, p. 204-205.

9 Barnsley, op. cit., p. 67-68.

10 K.A. Provins, "Motor Skills, Handedness and Behavior", in <u>Australian Journal of Psychology</u>, Vol. 19, No. 2, 1967, p. 146-147.

with each variable was not common to the other. Research findings reported in Chapter I were contradictory. While Palmer,[11] Benton, Meyers and Polder[12] and Annett[13] had supported a positive relationship between the consistency of preference and relative skill dimensions, Koch,[14] and Simon[15] had not. The results of this investigation supported the absence of any strong relationship between these variables. These findings coupled with the inconsistency of results reported by previous investigators intimate to this writer that at best a moderate positive relationship exists between measures of these views of handedness.

The data failed to suggest any significant degree of association between levels of preferred hand and differential skill. Unexpectedly, non-preferred hand levels of skill were found to be associated with levels of hand specialization on the majority of skill measures employed. Though inconclusive,

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11 Palmer, op. cit., 1967, p. 10.

12 A.L. Benton, R. Meyers, and G.J. Polder, "Some Aspects of Handedness," in Psychiatria and Neurologia, Basel, Vol. 144, 1962, p. 326-327.

13 M. Annett, "The Growth of Manual Preference and Speed," in British Journal of Psychology, Vol. 61, No. 4, 1970, p. 551.

14 H.L. Koch, "A Study of the Nature, Measurement, and Determination of Hand Preference," in Genetic Psychology Monographs, Vol. 13, 1933, p. 187-188.

15 Simon, op. cit., p. 205.

these results call into question most theorizing regarding the handedness phenomenon. That they replicated an earlier finding by Barnsley[16] also speaks for their possible reliability. If this is so, much thinking stressing that handedness is essentially a phenomenon characterized by and interested in preferred hand development needs to be reassessed and much more attention paid to the levels of proficiency of the non-preferred hand.

An attempt was made in Chapter I to provide a theoretical framework for definitions of handedness. Essentially, a link was postulated between the development of a consistent response bias in handedness and enhanced levels of hand skill. While the preferred and most proficient hands agreed in most subjects, substantive support for the hypothesis of a direct relationship between degrees of consistency in preference for the use of one hand and levels of skill in the preferred hand and levels of skill differences between the hands was not forthcoming. Greater levels of asymmetry in hand preference were not strongly associated in this study with the development of higher levels of preferred hand skill, nor with superior skill differences between the hands.

The findings of this research need be qualified in view of possible sources of error some of which escaped

16 Barnsley, op. cit., p. 69-70.

careful planning, while others became apparent as a result of this preliminary effort. The relatively small sample introduced several potential sources of error. Inadequate numbers of subjects were obtained to represent the full range of preference, particularly the many degrees of inconsistency. The small sample size was directly related to low power for the statistical F tests. The probability of finding significant differences was in most cases very low. Increases in sample and power should be prime considerations in future research. Findings need be considered as tentative and great care taken in their generalization.

Possible sources of error related to the experimental procedures are outlined below. It was previously mentioned that no entirely adequate hand preference questionnaire was available. Since the primary aim of this research was not to develop a hand preference measure, one deemed appropriate was selected and modified slightly. It was not practicable to include all tests suggested by previous factor-analytical studies in the assessment of hand skill, nor was it feasible to obtain data on the reliability of these skill measurements. In the administration of the skill tasks, no effort was made to control for the possible effects of experimenter bias. Future researchers might avail themselves of an assistant who would administer questionnaires and skill tests unaware of the real purpose of the investigation.

Order effects were found in the administration of the grooved peg board and finger tapping speed tests. On the former, difference scores and non-preferred hand scores were significantly affected. Results intimated that preferred hand practice improved non-preferred hand performance and, conversely, that P hand performance was not susceptible in a significant way to alternate hand practice. On the finger tapping task, order of administration significantly affected the P hand scores. The data suggested that transfer of training occured from NP to P hand performance, while the NP level of skill was not greatly affected by P hand practice. A randomization procedure for order of administration of each task to both preferred and non-preferred hands should obviate these difficulties in future studies.

Right-handers and left-handers who varied similarly in degree of consistency of hand preference were grouped together in this study for purposes of analysis. Though some justification was presented for this procedure, this writer acknowledges the potentially confounding influence of this pooling of subjects. Further research comparing the preferred hand and differential skill levels of right- and left-handers matched on consistency of hand preference scores seems warranted.

Limitations are recognized with regard to the generalization of these findings. The sample was small, representative of young to middle-aged adults, heavily weighted with right-handers and exclusively female in composition. Replication studies with more representative samples of both sexes as well as of the full hand preference continuum are necessary with adult as well as school-age populations. Relationships between these variables may be more apparent and/or more significant at earlier stages of development.

Potential sources of error relating to both sample and procedure were discussed and several suggestions were made. Additional recommendations for future research will be included in these final paragraphs of the discussion.

Prime emphasis should be given, in the opinion of this writer, to the investigation of basics: (1) the delineation of the various components of handedness, (2) the clarification of their interrelationships and contributions to the total phenomenon, and (3) the development of more adequate measures of both preference and proficiency conceptualizations of handedness. If consistent progress is to be made in relating handedness to other psychological phenomena, the achievement of a better understanding of the total phenomenon and of its component parts seems primordial.

Further investigation of suggested sex differences[17,18] in both hand preference and hand proficiency variables is needed.

A previous suggestion was made to the effect that the lack of adequate clarity in the definition and precision in the measurement of the handedness variable may have been largely responsible for the inconsistent research findings in this area. The results reported herein suggest that there may be no "simple" adequate definition of handedness. Subsequent researchers would be wise to attempt to specify in their investigations which component of handedness or dimension is being operationally defined and measured.

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17 Annett, op. cit., 1970b, p. 553.

18 Barnsley and Rabinovitch, op. cit., p. 360.

SUMMARY AND CONCLUSIONS

The main purpose of this research was to investigate the extent to which various definitions of handedness represent or describe equivalent phenomena. What is the relation between preferred and most proficient hands? Do individuals who vary in degree of consistency of hand preference vary similarly in levels of differential and preferred hand skill? The relation between the proficiency or skill definitions of handedness was also investigated.

While the data supported a strong predictive relationship between the preferred hand and the most proficient hand on several hand skill measures, groups differing in degree of consistency on a hand preference measure did not evidence significantly different levels of preferred hand skill. Significant differences were found between the hand preference measure and levels of relative skill between the hands on several skill tasks. However, the estimated degree of common variance between measures of the preference and differential skill variables was low in all cases. A hypothesized relationship between levels of preferred hand skill and differential skill was not supported. Unexpectedly, the levels of non-preferred hand skill on most proficiency measures were found to be significantly associated with relative skill values. The data of this experiment clearly failed to support any strong relationship between degree of consistency in hand preference, levels of preferred hand and levels of skill differences between the hands. These findings were qualified in view of potential sources of error. Limitations regarding the generalization of these results as well as suggestions for further research were also presented.

It is tentatively concluded on the basis of these preliminary results that measurements of these various conceptualizations of the handedness phenomenon possess in fact very little in common. They do not represent equivalent descriptions of handedness. On the contrary, the findings support the hypothesis that there exist many fairly independent sub-components which contribute differentially to the larger phenomenon of handedness. One obvious implication for researchers is that to define handedness in each of these various ways in investigating the relationships with other psychological phenomena may lead to very different results and conclusions.

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The author found support for the measurement of hand preference as a continuous variable and demonstrated a relation between consistency of preference and hand skill. She made novel use of the association analysis technique to justify the inclusion of certain items in a hand preference questionnaire.

--------, "The Growth of Manual Preference and Speed," in British Journal of Psychology, Vol. 61, No. 4, 1970, p. 545-558.

The article indicated that the distributions of hand preference and relative hand skill are constant between ages 3-1/2 and 15 years. The previously demonstrated relation between hand preference and relative hand skill was replicated in this study.

Barnsley, R. H., Handedness and Related Behavior, unpublished doctoral dissertation presented to the Department of Psychology, McGill University, Quebec, 1971, 145 p.

A factor-analytical study to identify the dimensions of hand skill in children. On the basis of the results, the author developed a scale for the measurement of a proficiency definition of handedness. He pioneered a definition of handedness as the level of preferred hand skill.

Barnsley, R. H., and M. S. Rabinovitch, "Handedness: Proficiency Versus Stated Preference," in Perceptual and Motor Skills, Vol. 30, 1970, p. 343-362.

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Palmer, R. D., "Development of a Differentiated Handedness," in Psychological Bulletin, Vol. 62, No. 4, 1964, p. 256-272.
The author reviewed the literature and argued that handedness need be viewed in the developmental perspective of gradual differentiation of motor skills. Particularly useful article in the development of a rationale for a proficiency definition of handedness.

--------, "Dimensions of Differentiation in Handedness," unpublished paper presented to the Eastern Psychological Association, Boston, 1967, 15 p.
A factor-analytical study which attempted to isolate those dimensions along which the hands become increasingly differentiated. The resulting factors were very general in nature.

Provins, K. A., "Motor Skills, Handedness and Behavior," in Australian Journal of Psychology, Vol. 19, No. 2, 1967, p. 137-150.
The author reviewed research on motor skills in terms of the underlying organization of muscle activity. He argued that motor skills are task-specific and develop from differential hand usage, thus questioning the validity of a general hand skill factor.

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Investigation of the relation between the relative skill of the preferred and non-preferred hands on a steadiness task. Superior preferred hand skill held only for right-handers.

APPENDIX 1

QUESTIONNAIRES EMPLOYED: ANNETT'S *HANDEDNESS RESEARCH QUESTIONNAIRE 2* AND THE *PHYSICAL DATA QUESTIONNAIRE*

APPENDIX 1

ANNETT'S HANDEDNESS RESEARCH QUESTIONNAIRE 2

Name ____________________________ Age ________ Sex ________

Where you one of twins, triplets at birth or were you single born? ___________

Please indicate which hand you habitually use for each of the following activities by writing R (for right), L (for left), E (for either).

Which hand do you use:

A. To write a letter legibly? ______________________________

B. To throw a ball to hit a target? ____________________

C. To hold a racket in tennis, squash or badminton?_________

D. To hold a match whilst striking it? _____________________

E. To cut with scissors? ___________________________________

F. To guide a thread through the eye of a needle (or guide needle onto thread? _____________________________________

G. At the top of a broom while sweeping? ___________________

H. At the top of a shovel when moving sand? ________________

I. To deal playing cards? __________________________________

J. To hammer a nail into wood? _____________________________

K. To hold a toothbrush while cleaning your teeth? _________

L. To unscrew the lid of a jar? ____________________________

If you use the RIGHT HAND FOR ALL OF THESE ACTIONS, are there any one-handed actions for which you use the LEFT HAND? Please record them here.

____

If you use the LEFT HAND FOR ALL OF THESE ACTIONS, are there any one-handed actions for which you use the RIGHT HAND? Please record them here.

____

APPENDIX 1

University of Ottawa

PHYSICAL DATA QUESTIONNAIRE

Name ....Age:.......years.......months

Sex ....Date......................Telephone..................

Address ....

This is a multiple-choice questionnaire. When completing each question, write between parentheses the letter which corresponds to the answer of your choice.

Sample Question

In which Faculty or School are you registered:

a) Arts b) Science c) Physical Education
d) Nursing e) Social Sciences f) Other (e)

The letter e between parentheses indicates this student is registered in the Faculty of Social Sciences.

1. What is your approximate height:

a) less than 5 ft. 4 in.
b) between 5 ft. 4 in. and 5 ft. 8 in.
c) between 5 ft. 8 in. and 6 ft.
d) over 6 ft. ( )

2. What is your approximate weight:

a) less than 100 lbs.
b) over 100 lbs and less than 125 lbs.
c) over 125 lbs and less than 150 lbs.
d) over 150 lbs and less than 175 lbs.
e) over 175 lbs. ( )

3. How is your eyesight:

   a) very good

   b) need to wear corrective lenses for some tasks only (e.g. reading or driving)

   c) wear corrective lenses most of the time ( )

4. How is your hearing:

   a) satisfactory

   b) need to use a hearing aid ( )

5. Assess your degree of physical fitness:

   a) below average

   b) average

   c) above average ( )

6. Are you interested in sports activities:

   a) very much c) slightly

   b) considerably d) not at all ( )

7. Do you actually participate in sports activities:

   a) frequently c) rarely

   b) occasionally d) never ( )

8. To write a letter legibly, you habitually use your:

   a) right hand b) left hand c) either ( )

9. To throw a ball to hit a target, you habitually use your:

   a) left hand b) right hand c) either ( )

10. To hold a racket in tennis, squash or badminton, you habitually use your:

    a) right hand b) left hand c) either ( )

11. To hold a match while striking it, you habitually use your:

    a) left hand b) right hand c) either ( )

12. To hammer a nail into wood, you habitually use your:

    a) right hand b) left hand c) either ( )

13. To hold a tooth brush while cleaning your teeth, you habitually use your:

    a) left hand b) right hand c) either ( )

14. When looking through a one-eyed telescope, you habitually use your:

    a) right eye b) left eye c) either ( )

15. When kicking a football or soccer ball as far as you can, you habitually use your:

    a) left foot b) right foot c) either ( )

16. When jumping for distance, you habitually make your final leap off your:

    a) left foot b) right foot c) either ( )

17. When firing a rifle to hit a target, you habitually aim with your:

    a) left eye b) right eye c) either ( )

18. To cut with scissors, you habitually use your:

    a) right hand b) left hand c) either ( )

19. To guide a thread through the eye of a needle (or guide the needle on the thread), you habitually use your:

    a) left hand b) right hand c) either ( )

20. At the top of a broom while sweeping, you habitually use your:

    a) right hand b) left hand c) either ( )

21. To deal playing cards, you habitually use your:

    a) left hand b) right hand c) either ( )

22. At the top of a shovel when moving sand, you habitually use your:

a) right hand b) left hand c) either ( )

23. To unscrew the lid of a jar, you habitually use your:

a) left hand b) right hand c) either ( )

24. How often do you suffer from headaches:

a) never c) occasionally

b) rarely d) frequently ( )

25. How often do you suffer from insomnia:

a) never c) occasionally

b) rarely d) frequently ( )

26. How often do you suffer from gastric indigestion:

a) never c) occasionally

b) rarely d) frequently ( )

27. At birth, were you:

a) single born b) one of twins c) one of triplets (

Are you physically handicapped in any way (i.e. total or partial blindness, total or partial deafness, muscular dystrophy, epilepsy, polio, etc.):

a) yes b) no ( )

If yes, please label or describe your physical handicap:

____

____

THANK YOU FOR YOUR COOPERATION!

APPENDIX 2

INSTRUCTIONS FOR THE ADMINISTRATION OF THE HAND SKILL MEASURES

APPENDIX 2

INSTRUCTIONS FOR MOTOR TESTS

1. Maze Coordination Test

Place maze on TPT stand with starting hole in lower right hand corner position. Stand and test are placed in mid-line of subject with edge of stand at edge of examining table so subject cannot rest his arm on the edge of the table. Power source is off.

Examiner says:

> In this test you are to take this stylus and put it in this opening here (starting position) and move it all the way through the maze up to here (point to end). The idea is to go through the maze without touching the sides. Go through the maze about this fast. (Examiner demonstrates about one quarter of the maze for speed.) If you go too fast, you will make extra mistakes. Remember, this is not a speed test. We don't want to see how fast you can go, but how carefully, without touching the sides. Try it first with this (preferred or non-preferred) hand. Make sure you do not rest your hand or arm on your side or on the stand, or brace it in any way.

Turn on power source. Subject performs task. After each trial, examiner turns off power source and records timer and counter scores on the scoring form.

2. Dynamometer Test

Present dynamometer to subject, saying:

> Would you hold this in your (preferred or non-preferred) hand; point it straight at the floor like this (demonstrate) and squeeze it as hard as you can.

> This time would you hold it in your (alternate) hand, point it straight at the floor, and squeeze it as hard as you can.

Repeat the procedure so that each hand has two trials, alternating each time between preferred and non-preferred hand.

Scoring.- If the difference between scores of each hand is within 3 kilograms, find the average of the two trials. If the difference between scores of each hand is greater than 3 kilograms, re-administer the test for both hands. To score, find the average of three trials for each hand.

Adjusting dynamometer handle: Average male = above 5
Average female = 4-5

3. Grooved Peg Board Test

Place peg board in midline of subject with board at edge of table and peg tray immediately above the board. Examiner says:

> What I want you to do is to put these pegs into the holes in this board. Notice that each hole and each peg has a groove along one side. To get the peg into the hole, you must turn the peg so the groove will match. Like this.

Examiner demonstrates one row from left to right and then removes pegs.

> When I say <u>go</u>, begin here (examiner points to upper left corner for right-handed subject, to upper right corner for left-handed subject) and put the pegs into the board as fast as you can, using only your (P or NP) hand. Fill the top row completely, going from here to here (examiner points left to right for right-handed subjects, right to left for left-handed subjects) before going on to the next row. In each row, always fill the board the same way you filled the top row. Ready, go.

Record time on scoring form.

Repeat procedure for non-dominant hand, with subject filling rows in direction opposite from trial 1.

4. Finger Tapping Test

> Now we are going to see how fast you can tap. We will use this little key here (show the subject). Place your arm and hand in a comfortable position

> like this, and without moving your wrist or arm, I want you to tap as fast as you can with your forefinger, like this. You will have to remember to let the key come all the way up and push it all the way down and click each time, or else it won't change the number on the dial. (Show subject how key works and how it should be allowed to click.) Now, move the board to a comfortable position for your (P or NP) hand, and try it for practice. (Allow a few seconds of practice.) I will tell you when to begin and stop each time. Remember now, tap as fast as you can. Ready, go.

Note.- The subject may rest his hand at any time, but insist that he rest after the third trial for each hand. Record the number of times subject taps in ten seconds. Discontinue when three consecutive scores within a range of 5 points are obtained. If three consecutive scores in a range of 5 points cannot be obtained, discontinue after ten trials and compute the mean tapping rate on the basis of the three scores which best reflect maximum performance. Repeat procedure for non-dominant hand.

APPENDIX 3

RAW SCORES FOR THE HAND PREFERENCE AND HAND SKILL MEASURES

APPENDIX 3

Hand Preference Scores

Subject	Hand Preference Index 1	Hand Preference Index 2	Performance Hand Preference Index
1	+1.00	+1.00	+1.00
2	+1.00	+1.00	+1.00
3	+1.00	+1.00	+1.00
4	+1.00	+1.00	+1.00
5	+1.00	+1.00	+1.00
6	+1.00	+0.76	+1.00
7	+1.00	+1.00	+1.00
8	+1.00	+1.00	+1.00
9	-1.00	-1.00	-1.00
10	+1.00	+0.88	+1.00
11	+1.00	+1.00	+1.00
12	+1.00	+1.00	+1.00
13	+1.00	+0.75	+1.00
14	+1.00	+1.00	+1.00
15	+1.00	+1.00	+1.00
16	+1.00	+1.00	+1.00
17	+1.00	+1.00	+1.00
18	-1.00	-0.88	-1.00
19	+1.00	+0.53	+0.53
20	+1.00	+1.00	+1.00
21	+1.00	+0.76	+1.00
22	+1.00	+0.88	+1.00
23	+1.00	+1.00	+1.00
24	+0.88	+0.18	+0.88
25	-0.76	-1.00	-0.76
26	+0.88	+0.37	+1.00
27	+0.88	+0.65	+0.76
28	+0.76	+0.59	+0.76
29	-0.53	-0.76	-0.76
30	+0.76	+0.76	+0.76
31	-0.76	-0.65	-0.65
32	+0.76	+0.88	+0.76

Subject	Hand Preference Index 1	Hand Preference Index 2	Performance Hand Preference Index
33	+0.76	+1.00	+0.88
34	+0.88	+1.00	+0.88
35	+0.76	+0.53	+0.76
36	-0.53	-0.58	-0.58
37	+0.88	+0.88	+0.88
38	-0.76	-0.76	-0.76
39	+0.76	+0.76	+0.76
40	+0.88	+0.88	+0.88
41	+0.88	+0.88	+0.88
42	+0.06	+0.06	+0.06
43	+0.41	+0.38	+0.63

Hand Skill Scores

Subject	Order of Administration	Maze Coordination Test Time in Contact Scores P	NP	P-NP
1	NP	12	59	-47
2	P	8	57	-49
3	P	8	97	-89
4	NP	5	14	- 9
5	NP	58	133	-75
6	NP	9	144	-135
7	P	36	109	-73
8	NP	36	147	-71
9	P	21	163	-142
10	NP	29	40	-11
11	P	42	287	-245
12	NP	44	100	-56
13	P	75	355	-280
14	P	6	55	-49
15	NP	13	96	-83
16	P	132	159	-27
17	NP	50	140	-90
18	P	94	140	-46
19	NP	0	92	-92
20	P	42	50	- 8
21	P	40	17	+23
22	P	11	24	-13
23	P	36	22	+14
24	NP	33	75	-42
25	NP	77	66	+11
26	P	62	116	-54
27	P	55	82	-27
28	NP	133	260	-127
29	NP	0	12	-12
30	P	20	53	-33
31	NP	28	60	-32
32	NP	54	0	+54

Subject	Order of Administration	Maze Coordination Test Time in Contact Scores		
		P	NP	P-NP
33	P	52	7	+45
34	NP	82	92	-10
35	P	110	153	-43
36	P	95	85	+10
37	P	30	127	-97
38	NP	51	50	+1
39	NP	0	48	-48
40	P	0	0	0
41	P	55	287	-232
42	P	0	5	-5
43	P	53	43	+10

Hand Skill Scores (Cont'd.)

Subject	Order of Administration	Maze Coordination Test No. of Contacts Scores		
		P	NP	P-NP
1	NP	2	7	-5
2	P	1	9	-8
3	P	1	10	-9
4	NP	1	2	-1
5	NP	5	14	-9
6	NP	1	12	-11
7	P	6	11	-5
8	NP	4	18	-14
9	P	3	18	-15
10	NP	2	4	-2
11	P	4	16	-12
12	NP	5	3	-3
13	P	5	30	-25
14	P	1	4	-3
15	NP	2	7	-5
16	P	14	9	+5
17	NP	7	10	-3
18	P	8	12	-4
19	NP	0	5	-5
20	P	5	5	0
21	P	5	2	+3
22	P	1	3	-2
23	P	3	4	-1
24	NP	2	6	-4
25	NP	4	10	-6
26	P	8	13	-5
27	P	6	7	-1
28	NP	16	28	-12
29	NP	0	2	-2
30	P	1	5	-4
31	NP	3	6	-3
32	NP	4	0	+4

Subject	Order of Administration	Maze Coordination Test No. of Contacts Scores		
		P	NP	P-NP
33	P	5	1	+4
34	NP	8	10	-2
35	P	8	14	-6
36	P	10	6	+4
37	P	5	13	-8
38	NP	3	4	-1
39	NP	0	5	-5
40	P	0	0	0
41	P	4	19	-15
42	P	0	1	-1
43	P	7	8	-1

Hand Skill Scores (Cont'd.)

Subject	Order of Administration	Hand Dynamometer Scores P	NP	P-NP
1	NP	34.00	31.25	2.75
2	P	29.62	26.75	2.87
3	P	29.5	28.25	1.25
4	NP	27.5	19.75	7.75
5	NP	32.25	25	7.25
6	NP	29	25.5	3.5
7	P	32	28.25	3.75
8	NP	31.25	25.5	5.75
9	P	28.17	31.75	-3.58
10	NP	44.5	39	5.5
11	P	28.75	21.25	7.5
12	NP	33.5	31	2.5
13	P	26.25	24.25	2
14	P	41.25	36.75	4.5
15	NP	26	21.83	4.17
16	P	37.25	30.75	6.5
17	NP	35.9	30	5.9
18	P	32	31.25	0.75
19	NP	36.5	29	7.5
20	P	39.6	32	7.6
21	P	40.8	34.5	6.3
22	P	33.5	29	4.5
23	P	32.5	30.5	2
24	NP	34.25	30.25	4
25	NP	26	24	2
26	P	25	24.75	0.25
27	P	34	24.75	9.25
28	NP	29	23.66	5.33
29	NP	25.5	31.5	-6
30	P	23	25	-2
31	NP	32.2	30	2.2
32	NP	29	26.25	2.75

APPENDIX 3

Subject	Order of Administration	Hand Dynamometer Scores		
		P	NP	P-NP
33	P	25.25	22.5	2.75
34	NP	24.75	18.5	6.25
35	P	26.5	22.75	3.75
36	P	30	29	1
37	P	27.75	23	4.75
38	NP	28.67	28.75	-0.08
39	NP	38.75	32.75	6
40	P	33.75	33	0.75
41	P	27.5	24	3.5
42	P	34.5	32.25	2.25
43	P	37.25	33.75	3.5

Hand Skill Scores (Cont'd.)

Subject	Order of Presentation	Grooved Peg Board Scores P	NP	P-NP
1	NP	58.5	66.5	-8
2	P	47.0	54	-7
3	P	48.5	54	-5.5
4	NP	62.7	68.5	-5.8
5	NP	52.5	65	-12.5
6	NP	55	64	-9
7	P	50.5	64	-13.5
8	NP	54.5	71	-16.5
9	P	70	79	-9
10	NP	-	-	-
11	P	44	48	-4
12	NP	54	62	-8
13	P	60	74	-14
14	P	53.5	61.5	-8
15	NP	47	59	-12
16	P	55	58	-3
17	NP	58.5	75.5	-17
18	P	54	65	-11
19	NP	69	68	+1
20	P	61	60	+1
21	P	61	57	+4
22	P	56	51	+5
23	P	55	54	+1
24	NP	64	78	-14
25	NP	59	68	-9
26	P	64	68	-4
27	P	47	60	-13
28	NP	65	79	-14
29	NP	54	70	-16
30	P	58.5	61.5	-3
31	NP	42	51	-9
32	NP	51	52	-1

Subject	Order of Presentation	Grooved Peg Board Scores P	NP	P-NP
33	P	63	73	-10
34	NP	46	59	-13
35	P	60	63	-3
36	P	52.5	61	-8.5
37	P	55	67	-12
38	NP	50	60.5	-10.5
39	NP	75	63	+12
40	P	64	57.5	+6.5
41	P	54	51	+3
42	P	54.5	51	+3.5
43	P	68	57.5	+10.5

Hand Skill Scores (Cont'd.)

Subject	Order of Presentation	Finger Tapping Speed Test P	NP	P-NP
1	NP	36.33	32.67	3.66
2	P	55.67	46	9.33
3	P	44.4	39.3	5.1
4	NP	49	42.67	6.33
5	NP	40	37.33	2.67
6	NP	35.33	30.33	5
7	P	45	41.67	3.33
8	NP	39.67	36.33	3.34
9	P	39.33	38.33	1
10	NP	45.67	40.67	5
11	P	48	40.3	7.67
12	NP	57.33	48.33	9
13	P	25.67	25	0.67
14	P	37.33	37.33	0
15	NP	44.67	40	4.67
16	P	43	33.67	9.33
17	NP	47	41	6
18	P	43.67	41.33	2.34
19	NP	59.33	49	10.33
20	P	33	39	-6
21	P	43.33	33	10.33
22	P	48.67	46.67	2
23	P	35.3	33	2.3
24	NP	52.57	46	6.67
25	NP	50.33	43.33	7
26	P	46	45.33	0.67
27	P	38.33	36.33	2
28	NP	51.33	38	13.33
29	NP	46.67	41	5.67
30	P	29	27	2
31	NP	46.67	39.33	7.34
32	NP	47.33	44	3.33

Subject	Order of Presentation	Finger Tapping Speed Test		
		P	NP	P-NP
33	P	43	37	6
34	NP	48.33	43	5.33
35	P	42.33	33.67	8.66
36	P	37	39.67	-2.67
37	P	54	54	0
38	NP	49.67	52	-2.33
39	NP	51.3	42	9.3
40	P	46	40.67	5.33
41	P	55	43.67	11.33
42	P	45.67	45.33	0.34
43	P	40	39	1

APPENDIX 3

Hand Skill Scores (Cont'd.)

Subjects	Hand Specialization Indices	Preferred Hand Skill Indices (P Hand Indices)	Composite Scores P	Composite Scores NP
1	50.35	51.14	0.346	-0.373
2	53.18	58.64	1.053	0.073
3	51.54	55.1	0.689	-0.214
4	53.72	51.87	0.409	-0.280
5	55.33	48.76	0.288	-0.910
6	55.46	50.59	0.249	-1.030
7	52.23	51.29	0.709	-0.459
8	57.32	49.58	0.290	-1.245
9	55.27	47.47	-0.137	-1.183
10	49.45	59.3	1.187	0.611
11	67.09	53.37	0.667	-1.086
12	52.04	54.42	0.977	0.019
13	62.54	39.47	-0.453	-2.496
14	48.25	56.57	0.833	0.213
15	53.04	53.33	0.566	-0.461
16	49.47	41.59	-0.021	-0.524
17	55.82	49.83	0.441	-0.865
18	48	45.52	0.136	-0.501
19	54.77	57.4	0.953	-0.441
20	42.74	48.36	0.356	0.091
21	48.54	51.8	0.706	0.292
22	44.39	55.63	0.778	0.565
23	42.93	49.30	0.237	0.123
24	52.94	51.91	0.559	-0.322
25	49.63	46.85	0.159	-0.514
26	45.55	42.51	0.220	-0.678
27	53.92	50.11	0.416	-0.434
28	62.20	36.74	-0.42	-2.143
29	44.92	53.66	0.502	0.103
30	43.53	43.09	-0.295	-0.573
31	50.65	56.27	0.888	0.176
32	41.58	50.71	0.453	0.559

Subjects	Hand Specialization Indices	Preferred Hand Skill Indices (P Hand Indices)	Composite Scores P	Composite Scores NP
33	45.55	44.32	0.0002	-0.393
34	51.9	46.8	0.215	-0.636
35	51.52	40.44	-0.311	-1.114
36	40.74	42.14	-0.169	-0.170
37	52.54	51.76	1.273	-0.196
38	45.79	52.22	0.575	0.358
39	49.09	54.46	0.666	0.140
40	42.13	54.02	0.585	0.560
41	59.47	51.34	0.538	-1.058
42	41.52	56.81	0.847	0.772
43	40.78	45.70	0.054	0.137

APPENDIX 4

ABSTRACT OF

Preference and Proficiency Definitions of Handedness: A Comparative Study

APPENDIX 4

ABSTRACT OF

Preference and Proficiency Definitions of Handedness: A Comparative Study[1]

A review of pertinent literature highlighted the variety of operational definitions of handedness and underscored the conceptual diversity associated with this phenomenon. Operational definitions of handedness as consistency of preference and as levels of both preferred hand and skill differences between the hands seem to have gained the greatest popularity among researchers. The main purpose of this study was to investigate the extent to which these preference and proficiency definitions of handedness represent or describe equivalent phenomena.

A modified version of Annett's Handedness Research Questionnaire 2 was selected to tap the consistency of preference dimension, while scores on four standard hand skill tests were measures of the proficiency definitions. Several comparisons were made: (1) between the preferred hand and most proficient hand; (2) between groups of consistent, moderately inconsistent, and inconsistent handers in terms of (a) the

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1 Brian G. MacKinnon, Master of Arts thesis presented to the School of Graduate Studies of the University of Ottawa, Ontario, March 1974, xi-154 p.

frequency of agreement between preferred and non-preferred hands, (b) the levels of differential skill scores, and (c) the levels of preferred hand skill scores; (3) between levels of preferred hand and differential skill scores.

Findings supported a strong predictive association between the preferred and most skillful hands. The data, however, clearly failed to support any high degree of association between degree of consistency in hand preference, levels of preferred hand skill and levels of differential hand skill. The non-preferred hand skill scores were found unexpectedly to relate more highly to the levels of relative skill scores than did the preferred hand scores.

Given the limitations of this study, it was tentatively concluded that measurements of three definitions of handedness share little in common. Findings thus support the view that there exist a number of fairly independent components which contribute differentially to the larger phenomenon of handedness.