5-1989

Neuroanatomical Asymmetry, Handedness, and Family History of Handedness : A Study of the Markers of Structural and Functional Lateralization

Steven A. Lifson
Utah State University

NEUROANATOMICAL ASYMMETRY, HANDEDNESS, AND FAMILY HISTORY OF HANDEDNESS: A STUDY OF THE MARKERS OF STRUCTURAL AND FUNCTIONAL LATERALIZATION

By

Steven A. Lifson

A dissertation submitted in partial fulfillment of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Psychology

UTAH STATE UNIVERSITY

Logan, Utah

1989

ACKNOWLEDGEMENTS

I am indebted to Dr. Damian McShane for allowing me to participate in this research and for the advice and discussion that took place throughout the course of the project. Thanks too to Dr. Bertoch for the wherewithal to complete the project in and for support during the later stages. To Teri Peterson, thanks for the statistical guidance and the boldness (impatience?) to say "Enough analysis! Write already!" and other words to that effect. Thanks to the other denizens of the Breezeway Computer Lab for assistance and support. Sam Maesato also deserves a great deal of credit for the generous extension of his time and for allowing me access to the CT equipment in those days before my internship departure.

Special thanks are due for the unfailing support, friendship, and encouragement of Dr. William R. Dobson, who always seemed to be there when I truly needed him. My thanks are likewise extended to Dr. Phyllis Cole, former supervisor, friend, and fearless *noodj*.

To my friends, colleagues, brothers and sisters in life, the profession, and avoidance behaviors: Yes, it can be done!

To the everflowing coffee bins of the Straw Ibis and the big ears of the sales staff, thanks for your tolerance (and support) of a raving caffeine freak! You were a warm place in my wanderings.

Finally, to my parents, without whose love and support none of this would have been possible: the last words will always be to and of you.

Steven Adam Lifson

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS ii

LIST OF TABLES v

LIST OF FIGURES viii

ABSTRACT x

CHAPTER Page

I INTRODUCTION 1

Problem Statement 3
Rationale 7

II REVIEW OF THE LITERATURE 8

Introduction 8
Animal Studies 8
Neuroanatomical Asymmetry 10
Functional Lateralization 14
The Assessment of Handedness 19
Measurement of CT Scans 20
Purpose 21
Independent Variables 22
Hypotheses 23

III METHODOLOGY 24

Experimental Design 24
Subjects 26
Assessment of Handedness 31
Measurement of CT Scans 33

IV RESULTS 42

Description of the Sample 42
Differences Between Trace
and Console Data 43
Mean Differences Between Handedness
Groups 51
Differences in Frequencies of Asymmetry
by Handedness 81
Interactions Between Asymmetries at Anterior
and Posterior Points of Opposite
Hemispheres 99
Possible Confounds 102

Summary of Results 108

V DISCUSSION 110

Major Findings 111
Summary 122
Limitations and Suggestions
for Future Research 124

REFERENCES 128

APPENDICES 134

Appendix A. Protocol for Telephone Interview 135
Appendix B. Questionnaire for Brain
Asymmetry Study 136
Appendix C. Cover Letter and Insert 139
Appendix D. Consent Form Included with
Questionnaire and Cover Letter 141
Appendix E. Tables 142

VITA 186

LIST OF TABLES

Table | Page

1. Neuroanatomical Asymmetries in the Human Brain 11
2. Mean Ages and Descriptive Statistics of Ages by Handedness and Family History Groups, Trace and Console Data 27
3. Frequencies and Percentages of Referral Question Categories for the Traced Subjects and Handedness Categories (number/percent) 28
4. Frequency and Values for the Whole Sample and Groups on Alcohol Use and CT Finding 30
5. Structures on the Level of the CT Scan and Their Approximate Position on the Anterior-Posterior Line 40
6. T-Test Comparisons of Trace and Console Data Sorted by Handedness Groups 48
7. Analysis of Variance F Values and Associated Significance of CT Trace and Console Data Right- and Left-Hemisphere Widths 58
8. Analysis of Variance F Values and Associated Significance of CT Trace and Console Data, L÷R Ratios 62
9. Analysis of Variance F Values and Associated Significance of CT Trace and Console Data Left-Right Difference Measures 67
10. Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Traced Subjects (n=108) 70
11. Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Traced Right-Handed Subjects (n=68) 71
12. Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Traced Righthanders w/ Left Relatives (n=24) 72
13. Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Traced Left-Handed Subjects (n=16) 73

14. Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Console Subset (n=69) 74

15. Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Console Subset, Right-Handed Subjects (n=49) 75

16. Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Console Subset, Right-Handers with Left-Handed Relatives (n=14) 76

17. Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Console Subset, Left-handed Subjects (n=6) 77

18. Chi-Square Frequencies of Asymmetry in the Handedness Groups, 75% of AP (Trace) 81

19. Chi-Square Frequencies of Asymmetry in the Handedness Groups, 67% of AP (Trace) 82

20. Chi-Square Frequencies of Asymmetry in the Handedness Groups, 60% of AP (Trace) 89

21. Chi-Square Frequencies of Asymmetry in Handedness Groups, 20% of AP (Trace) 89

22. Chi-Square Frequencies of Asymmetry in the Handedness Groups, 10% of AP. (Console) 91

23. Chi-Square Frequencies of Asymmetry in the Handedness Groups, 80% of AP (Console) 92

24. Chi-Square Frequencies of Linked Occipital/Frontal Asymmetry Types in Right- and Left-Handed Subjects 101

25. Chi-square Frequencies of Linked Posterior Temporal/ Temporal Frontal Asymmetry Types in Right- and Left-Handed Subjects 102

E1. Descriptive Statistics of the Measurement Variables for the Trace Subjects, Console Subjects, and the Three Handedness Groups 143

E2 Analysis of Variance F Values and Associated Significance of CT Trace Measures 162

E3 Analysis of Variance F Values and Associated Significance of CT Console Measures 170

E4. Chi-Square Frequencies of Asymmetry in the Handedness Groups (Trace) 178

E5. Chi-Square Frequencies of Asymmetry in the Handedness Groups (Console) 182

LIST OF FIGURES

Figure | Page

1. Axial view of CT section of brain. 36
2. Lobes of the brain in lateral view. 37
3. Lateral cutaway view of internal landmarks in the brain relative to anterior-posterior line and level of scan. 38
4. Lateral view of the brain showing selected functional cytoarchitectonic areas. 39
5. Cell means of the measurement method by handedness group (80% AP). 46
6. Cell means of the measurement method by handedness group (75% AP). 47
7. Trace left-hemisphere widths by handedness group. 52
8. Console left-hemisphere widths by handedness group. 53
9. Trace right-hemisphere widths by handedness group. 55
10. Console right-hemisphere widths by handedness group. 57
11. L÷R ratios by handedness group, trace data. 61
12. Console L÷R ratios by handedness group. 63
13. L-R differences by handedness group, trace data. 65
14. Console L-R differences by handedness group. 66
15. Percentages of asymmetries for right-handed subjects, trace data. 83
16. Percentages of symmetrical difference measures for right-handed subjects, trace data. 84
17. Percentages of left and right asymmetries for right-handed with left-handed relatives, trace data. 85

18. Percentages of symmetrical difference measures for right-handed with left-handed relatives, trace data. 86

19. Percentages of left and right asymmetries for left-handed subjects, trace data. 87

20. Percentages of symmetrical difference measures for left-handed subjects, trace data. 88

21. Percentages of left and right asymmetries for right-handed subjects, console data. 93

22. Percentages of symmetrical difference measures for right-handed subjects, console data. 94

23. Percentages of left and right asymmetries for right-handed with left-handed relatives, console data. 95

24. Percentages of symmetrical difference measures for right-handed with left-handed relatives, console data. 96

25. Percentages of left and right asymmetries for left-handed subjects, console data. 97

26. Percentages of symmetrical difference measures for left-handed subjects, console data. 98

ABSTRACT

Neuroanatomical Asymmetry, Handedness, and Family History of Handedness: A Study of the Markers of Structural and Functional Lateralization

By

Steven A. Lifson, Doctor of Philosophy

Utah State University, 1989

Major Professor: Dr. Damian McShane

Department: Psychology

This study investigated the associations between (1) handedness (demonstrated preference of one hand for the performance of most unimanual tasks) and neuroanatomical asymmetry (measurable differences in width between the cerebral hemispheres) and (2) familial history of handedness (the presence of a left-handed sibling or parent of a right-handed subject) as an intervening factor in the relation between handedness and neuroanatomical asymmetry. Width measurements of the brain were derived from computerized tomographic (CT) films and grouped into categories by hand preference (measured by the Edinburgh Handedness Inventory) and family history. The measurements of right (n=68), right with left-handed relatives (n=24), and left-handed (n=16) groups were then compared by width and other transformations of the brain measurements. Subjects were adults of both sexes who had been referred for neurologic examination and were diagnosed as free of major distorting brain pathology. Hemispheric widths were compared by group, as ratios (left÷right) and as differences (left-right).

Analysis of variance revealed significant differences between right-hemisphere widths at three percentages of brain length in the posterior occipital and temporal-parietal portion of the right hemisphere. The two right-handed groups had significantly smaller right-hemisphere measurements than the left group at 80% ($p = .03$), 75% ($p = .012$), and 60% ($p = .029$) of brain length. There were no significant left-hemisphere differences between the groups. In terms of ratios of sides and differences between sides in the same brain region, the left-handed group was different from the right-handed group at the $p < .05$ level at 80%, 75%, 67%, and 60% of brain length. The family history variable did not distinguish the two right-handed groups from each other. Overall, the right-handers had wider posterior-left hemispheres, left-handers had the same-sized left hemisphere as the right-handers, but the posterior-right hemisphere of the left-handers was bigger than that of the right-handers. The relatively larger right hemisphere of the left-handers made the brains of these subjects appear more symmetrical.

Handedness appears to be moderately associated with neuroanatomical asymmetry. The differences in sizes of brain structures and their relation to functionally lateralized abilities may shed light on the processes by which each hemisphere becomes specialized to perform specific tasks and other aspects of individual differences.

(198 pages)

CHAPTER I

INTRODUCTION

Perhaps the observations that launched the scientific study of hemispheric specialization were made by independently working French physicians Dax (1836) and Broca (1861). Both concluded that aphasia is associated with damage to the left hemisphere of the brain due to the presence of right hemiplegia and postmortem findings of lesions on the left side of the brain (Springer & Deutsch, 1985). Broca proposed the rule of thumb that the hemisphere opposite the preferred hand is dominant for speech. This was the first link made between functional lateralization (as opposed to neuroanatomical asymmetry) in the brain and hand preference.

Broca's rule for lateral dominance for speech was challenged by the observations of Hughlings Jackson, who noted a case of aphasia with left hemiplegia (Corballis, 1983). By 1899 (Bramwell, 1899, cited in Galaburda, LeMay, Kemper, & Geschwind, 1978) the term crossed aphasia was being used to describe cases in which dominance for speech seemed to depart from the hemisphere-opposite-preferred-hand rule.

With Broca's rule proving faulty, it became important to determine the distribution of hemispheric lateralization for speech. A more recent estimate of speech lateralization, made with the Wada test (a process whereby one hemisphere at a time is anesthetized while the patient is questioned), produced the finding that fully 70% of all left-handers seem to be left dominant for speech compared with right-handers, more than 95% of whom appear to have left-hemisphere representation for that ability (Corballis, 1983). Studies of patients receiving electro-convulsive therapy (ECT) where the application of the shock is unilateral (a widely used variant of this treatment that seems to reduce memory loss) have produced similar results (Corballis, 1983). These studies suggest left-hemisphere dominance for speech regardless of preferred hand.

Functional lateralization for speech became accepted relatively early. In contrast, structural asymmetry was assumed to be random, minor, and inconsequential (von Bonin, 1962, cited in Galaburda et. al., 1978). Functional lateralization for speech was not believed to have an anatomical basis, and the findings of earlier researchers (Eberstaller, 1884; and Cunningham, 1892 cited in Galaburda et. al., 1978) were ignored. However, Geschwind and Levitsky (1968) found 65% of their sample of brains examined postmortem to have larger planum temporales in the left hemisphere. This site, an area on the upper surface of the temporal lobe located within Wernickes area, was found to be larger on the right in 11% of the cases, equal in size in both hemispheres in 24% of the cases, and larger on the left in 65%. Geschwind and Galaburda (1984) noted that the percentage of brains with larger planum temporales on the left side seems far too low, considering functional lateralization findings of the Wada test and ECT studies cited earlier, if one is trying to make an association between the functional lateralization of speech and anatomical asymmetry. The latter studies suggest overwhelming left-hemisphere dominance for speech. However, Luria (1970) observed that while nearly all patients with penetrating wounds in the speech areas are aphasic at the outset, 30% show good recovery in a year. This group contains a high proportion of left-handers and right-handers with left-handed relatives. Galaburda and Geschwind (1984) suggested that the 35% with larger right planum temporales or bilateral equality may constitute this group, a group with anomalous lateralization for speech. The structural evidence, then, might suggest to some that the number of people with anomalous lateralization for speech may be much larger than previously thought.

Problem Statement

Beginning with the observations of Dax and Broca on aphasiacs (Springer & Deutsch, 1985), it has been known that the human brain is functionally lateralized for abilities ranging from speech to spatial perception. Despite the acceptance of functional lateralization, neuroanatomical symmetry of the brain was an assumed fact until as late as the 1960s (Galaburda et. al., 1978). Geschwind and Levitsky's (1968) finding of a marked neuroanatomical asymmetry in the region of the planum temporale (an area connected with the production and comprehension of speech) stimulated renewed inquiry into anatomical correlates of functional lateralization.

The issue of the relation between neuroanatomical asymmetry and functional lateralization achieved new importance when research appeared that suggested that these traits are not characteristic of human brains alone. Recent studies (Glick, 1985) have found evidence of functionally lateralized abilities that relate to many aspects of behavior in nonhuman species. Furthermore, data from animal studies suggest that there may be relations between age, gender, and anatomical asymmetries in the brain (Diamond, 1984, 1987). The accumulation of evidence suggests that neuroanatomical asymmetry and functional lateralization in the brain may be the rule rather than the exception across species (Galaburda et. al., 1978; Geschwind & Galaburda, 1984; 1985a).

Differences in individual hand preference in humans have long been associated with other more subtle differences in performance and ability. In humans, handedness is associated with differing degrees of functional lateralization. Left-handers are less functionally lateralized in abilities on the whole (Hicks & Kinsbourne, 1978). In addition, left-handedness is associated with higher proportions of reading problems, learning disabilities, immunological disorders, migraine, an improved prognosis of recovery from aphasia, and certain kinds of talents (Bradshaw & Nettleton, 1983; Geschwind & Galaburda, 1984; Luria, 1970; Satz, 1980).

LeMay and her associates (LeMay 1976; 1977; LeMay & Culebras, 1972; LeMay & Kido, 1978; Hochberg & LeMay, 1974) suggested that handedness may be one expression of significant differences in the neuroanatomical organization of the brain. LeMay (1977) found evidence for "counter-clockwise torque" in the brains of right-handers; that is, the right frontal lobe tends to be wider than the left, and the left occipital lobe tends to be wider than the right. (Torque refers to a visual image of how the brain would look if it had been spun in a particular direction and the material of which the hemispheres is composed had flowed slightly along the plane of rotation.) This pattern was not found in left-handers, who are more symmetrical on the whole with a small trend toward torque in the opposite (clockwise) direction. Although insufficient data are available, sinistrals with sinistral first-degree relatives seem to form a different group from nonfamilial sinistrals. Chui and Damasio (1980) and Deuel and Moran (1980) reported similar directions of asymmetry in the brains of their subjects, but these asymmetries were not in high enough proportions to significantly correlate with handedness. Both of these studies concluded that dextrals and nondextrals are not distinguished by specific patterns of neuroanatomical asymmetry. Deuel and Moran (1980) specifically questioned any attempt to relate developmental learning disorders to reversal of cerebral asymmetries (e.g., Hier, LeMay, & Rosenberger, 1978, who attempted to relate such reversals to developmental disorders like dyslexia). Considering the lack of standardization of methodology in the three studies, drawing definitive conclusions is premature.

A number of problems in the studies carried out by LeMay (1977), Chui and Damasio (1980), and Deuel and Moran (1980) prevent conclusive interpretation of their findings. First, the methodology is not standardized. Deuel and Moran did not explicitly describe how their brains were measured. Chui and Damasio took two measurements on the anterior-posterior (AP) line drawn through the anterior falx, septum pelucidum, and pineal gland. Perpendiculars were drawn from the AP line to the inner table of the skull at 16% and 90% of the AP length. It is possible that this measurement method was not sufficiently sensitive to the neuroanatomical asymmetries it was meant to detect, due to the limited number of measurement points, and therefore resulted in too many false-negative findings.

Second, relevant sample variables were not studied. Deuel and Moran did not report on family history of handedness, and LeMay (1977) lacked sufficient data to properly study this aspect. As a rule, the subjects in these studies had higher rates of medical problems, a consequence of recruiting hospital patients as subjects and a potential threat to internal and external validity (Filskov & Locklear, 1982). Deuel and Moran (1980) reported that 71% of their sample may have had seizure disorders, a factor that may have influenced their findings. Other researchers in this area (McRae, Branch, & Milner, 1968) have noted that individuals with seizure disorders may differ significantly in the neuroanatomical symmetry dimension from individuals lacking that characteristic.

Finally, the ethnic make-up of study samples has not generally been reported. As McShane and Willenbring (1984) and McShane, Risse, and Rubens (1984) found, this variable may be significant. Preliminary evidence that there are ethnic variations in neuroanatomical asymmetry (McShane & Willenbring, 1984; McShane, 1983; McShane et al., 1984) indicates a need for the delineation of the influence of this variable as well. In addition, alcoholism may influence the degree of neuroanatomical asymmetry (McShane & Willenbring, 1984). If the effects of gender, handedness, and ethnicity are not accounted for, the study of neuroanatomical asymmetry in the brain and its relation to functional lateralization may be confounded by these variables.

Rationale

In a series of recent articles, Geschwind and Galaburda (1985a, b, c) proposed a theory of the biological mechanisms of functional lateralization and neuroanatomical asymmetry. This theory attempts to tie functionally lateralized abilities to neuroanatomical asymmetry and to explain the greater frequencies of developmental disorders of language, speech, cognition, and emotion in males. The theory also attempts to explain the greater prevalence of these same disorders in left-handers. Central to the theory is the idea that factors that disrupt the assumption of certain abilities by the left hemisphere result in a group with anomalous dominance. The term anomalous dominance refers to a group that, in functionally lateralized and neuroanatomical characteristics, differs from the majority pattern. The need for the present study lies in the failure of previous studies to decisively establish a connection or the lack of one between handedness and anomalous patterns of neuroanatomical asymmetry. The identification of a neuroanatomically anomalous group that includes, but is not restricted to, left-handers would extend the findings of other investigators and relate more directly to the suggested theoretical framework.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

The purpose of this section is to support the need for this study. Neuroanatomical asymmetry and functional lateralization research in animals and humans is reviewed in an attempt to illustrate the pervasiveness of these two phenomena across functions and structures.

The characteristic of handedness in humans is discussed in some detail along with the uncertainties involved in measuring it. Attention is also paid to methods used to measure brains in previous studies.

Animal Studies

Neuroanatomical asymmetry and functional lateralization have recently been studied in nonhuman species. Diamond (1984; 1987) found significant differences in neuroanatomical asymmetry between male and female rats. These differences were found on cortical and subcortical levels. Female rats tend to have a far greater degree of symmetry in the paired neuroanatomical structures than the males. Neuroanatomical asymmetries have also been found in various species of fish, reptiles, and amphibians (Geschwind & Galaburda, 1984). LeMay and Geschwind (1975, cited in LeMay, 1985) found that the chimpanzees in their sample had longer, straighter Sylvian fissures on the left in a significant number of cases. LeMay (1985) found right frontal petalia in 62%, left frontal petalia in 25%, and equality in 15% of her sample of gorillas. Similar results were found in chimpanzees. Evidence for neuroanatomical asymmetry in New- and Old-World monkeys is not as strong (LeMay, 1985).

Functional lateralization in many species of birds has been strongly suggested by the work of Nottebohm and Nottebohm (1976). Nottebohm and others have found evidence for unilateral control of the paired singing organs in the canary and other passerine birds. Collins (1985) reported that degree of lateralization (as reflected in "pawedness") in mice can be influenced by selective breeding. While the basic proportion of rats preferring a given paw does not change (remaining 50% right/left preference); the degree, consistency, and strength of the preference is strongly influenced by selective breeding. The work of Collins has influenced some (Bryden, 1982,1987) to propose that it is strength of handedness (lateral preference) that is inherited, not direction. Denenburg (1981) reported evidence for right functional lateralization for spatial function and emotion in rats. More controversial is the evidence for functional lateralization in rhesus monkeys (Hamilton, 1977; Denenburg, 1981; Springer & Deutsch, 1985). However, MacNeilage (1987) reviewed and reinterpreted previous research and gave new evidence of population-level lateral preferences in higher primates for left-hand prehension with a complementary postural specialization for right-side limbs.

These findings strongly suggest that asymmetry in structure and function is not characteristic of humans alone. Functional lateralization and neuroanatomical asymmetry may in fact be fundamental characteristics across species. The significance of these pervasive phenomena is not yet understood.

Neuroanatomical Asymmetry

One of the most important of the studies related to the search for anatomical correlates to functional asymmetry is Geschwind and Levitsky's (1968) finding of a longer left planum temporale in the majority of the brains examined (See Table 1 for a summary of some of the relevant research on neuroanatomical asymmetry). The study does not report the impact of handedness on this finding due to a lack of handedness data for the subjects. McRae, Branch, and Milner (1968) studied the pneumoencephalograms of 100 neurological patients whose handedness was known. Of the right-handed group, 60% had longer left occipital horns, 30% had equal occipital horns, and 10% had horns that were longer on the right. Unfortunately, there were too few sinistrals for meaningful analysis. LeMay and Culebras (1972) and Hochberg and LeMay (1974) found right-left hemisphere differences in vascularization that had a significant relation to the handedness of the subjects. In a dextral group (106 subjects), 67% had more sharply angled arches formed by the branches of the middle cerebral artery in the left hemisphere, 25.4% had equally angled arches in both hemispheres, and about 7.5% had arches that were angled more sharply on the right. In the sinistral group (28 subjects) 21% had more sharply angled arches in the left hemisphere, 71% had equally angled arches in both hemispheres, and 7.1% had more sharply angled branches in the right hemisphere. The vascular differences found have an impact on the length and configuration of

Table 1

Neuroanatomical Asymmetries in the Human Brain

Author, Structure	Right hand L>R	L=R	R>L	Left hand L>R	L=R	R>L	# Right, Left
Frontal Lobe							
LeMay '77	19	20	61	26.6	33	40	120, 124
LeMay & Kido '78	12	24	58	30	34	35	80, 85
McShane & Willenbring '84	14	46	40	No handedness data taken			
Chui & Damasio '80	8	56	36	16	56	28	50, 25
Occipital Lobe.							
LeMay '77	66	24	11	36	42	26	120, 124
LeMay & Kido '78	71	20	9	34	34	32	80, 85
Chui & Damasio '80	60	20	20	44	36	20	50, 25
McShane & Willenbring '84	68	22	11	No handedness data taken			
Planum Temporale							
Geschwind & Levitsky '68	65	24	11	No handedness data			100
Wada, Clarke, Hamm '75	82	8	10	No handedness			100 adults
Wada et al. '75	56	32	12	No handedness			100 infants
Witelson & Pallie ' 73	69	0	31	No handedness			14 adults
Length/Angle of Sylvian Fissure							
LeMay & Culebras '72	5	9	86	11	72	17	44, 18
Hochberg & LeMay '74	7	26	67	7	71	22	100, 28
Ratcliff et al. '80	21	21	58	15	35	50	38, 20
Occipital Horn							
McRae et al. '68	60	30	10	38	31	31	87, 13
Strauss & Fitz '80	39	44	17	No handedness data			75
Bulbar Pyramids							
Kertesz & Geschwind '71	73	10	17	86	0	14	123, 7

the Sylvian fissure. Basically, dextrals had a mean angulation difference between the left and right Sylvian point angles of 23.5 degrees, with the left fissure being longer and more horizontal (the posterior endpoint was lower). In contrast, sinistrals had much smaller mean angulation differences between the right and left Sylvian points. In the sinistral group the mean angulation difference between left and right Sylvian points was 6.6 degrees. Thus, the left-handed subjects showed a greater tendency toward symmetry than the right-handed group. In the actual breakdown of measurements in the left-handed sample, 20 of 28 brains had points of equal height, 6 had a higher right point (the dextral pattern), and 2 had a higher left Sylvian point. This study illustrates the observation that neuroanatomical asymmetries present in right-handers are less marked in left-handers. Left-handers seem to be more symmetrical in their neuroanatomical organization.

LeMay (1977) observed what she described as torque in neuroanatomical features of the brain via computerized tomography (CT scans). She studied axial scans of 120 dextral and 124 sinistral patients and measured the indentations (petalia) on the inner table of the skull at the frontal and occipital poles. LeMay found that 61% of the right-handers had wider right frontal lobes; 19% had wider left frontal lobes. At the occipital pole, 66% had wider left occipital lobes, and 11% had wider right occipital lobes. Forty percent of the sinistral subjects had wider right frontal regions, and 26.6% had wider left frontal regions. In the occipital region, 36% had wider right lobes. LeMay noted that left-handers who lacked left-handed first-degree relatives tended to have brains with the same percentages of asymmetry as the brains of right-handers, although insufficient numbers of these subjects were available for meaningful analysis. Other researchers (Deuel & Moran, 1980; Chui & Damasio, 1980) have found similar proportions of asymmetries with similar (but not identical) methods but have not found significant relations between handedness and neuroanatomical asymmetries.

Witelson and Kigar (1987a, 1987b) provided extensive evidence of significant differences in the sizes of the corpus callosa between right- and mixed-handers. In the same studies, gender was also addressed as a factor in callosal size but was found to be "neither marked nor reliable" (1987a, pg. 490). Witelson and Kigar did not attempt to associate the finding of an enlarged corpus callosum with specific functional lateralization differences between right- and mixed-handed subjects. They also stated that they did not know whether the increased dimension of the callosal pathway in mixed-handers is due to a greater number of fibers or some other characteristic (such as thicker myelin sheaths). Among the interesting implications of the findings of Witelson and Kigar is that left- and mixed-handed individuals may have greater "traffic" in neural communication between the hemispheres. The size difference in the callosum is especially marked in the posterior part of the body of the callosum. The authors reported that this area is associated with transmission between areas of the brain known to be involved in mediating cognitive functions that have lateralized representation. No studies relate the corpus callosum findings with other known asymmetries associated with the handedness variable.

Functional Lateralization

Handedness

Handedness is one of the most striking examples of a functionally lateralized ability. Asymmetrical hand preference, by direct and indirect evidence, is a human characteristic across groups and across the history of the species (Hicks & Kinsbourne, 1978; Springer & Deutsch, 1985; Corballis, 1983; Coren & Porac, 1977). The percentage of the population that prefers to use the right hand for skilled activities (dextrals) is about 90%, varying to an extent with the method used for assessment. The incidence of left-handedness has been estimated to range from 2-12% of a given population, varying, according to Corballis (1983), with the degree of social pressure to use the right hand.

The origin of handedness has been variously attributed to genetics, environment, chance, combinations of the previous three, and another factor that may be a side effect of the process whereby the brain becomes lateralized in the first place—developmental but not genetic in and of itself (Geschwind & Galaburda, 1985a). Supporting the genetic hypothesis, Hicks and Kinsbourne (1976) found a significant correlation between hand preference in college students and the hand preferences of their biological parents and no correlation with the hand preferences of stepparents. Annett (1973, 1974, 1978) and Levy and Nagylaki (1972) proposed differing models for the genetic control of handedness.

Annett's (1972, 1973, 1975, 1987) model proposes that left-handers are the minority who lack a dominant allele for the right-shift factor, with this group having an approximately equal chance of being dextral or sinistral. The right-shift (rs+) gene is hypothesized to give the left hemisphere a relative advantage over the right early in the course of development. This advantage is directed toward giving the left hemisphere dominance in control over speech. According to Annett, right-hand preference may be a side effect of the gene that promotes the development of left-hemisphere speech. She speculated that a double dose of the rs+ gene may have relative disadvantages stemming from overcommitment to left hemisphere resources in those with that genotype (rs++), leading to selective pressure for the homozygous condition (rs+-). The recessive condition (rs--) results in no systematic bias toward speech for either hemisphere and leaves the issue of hand preference to chance and environmental factors.

Annett speculated that the majority of individuals with rs-- will be right-handed due to environmental pressures. Annett's theory places the emphasis on genetic control of the lateralization of speech and allows for the possibility of mixed-handedness in all genotypes. As in most theories on the genetic origin of handedness, there is no specific explanation of the differing rates of left-handedness in twins (Bryden, 1982). Any simple genetic model would call for monozygotic twins to have identical handedness. In fact, discordant handedness is observed in twins rather more frequently than one would expect. Bryden cited research that reports up to 23% of monozygotic twins and 21% of dizygotic twins displaying discordant handedness. Annett (1987) attempted to deal with this problem by speculating about stresses in the uterine environment arising from the presence of two embryos (a leaf from the position that is taken by Bakan, 1972, 1977, below). However, extensive research by Nachshon and Denno (1987) suggests that birth stress and lateral preference are not related.

Levy and Nagylaki's (1972) model for the inheritance of dominance for speech and handedness is much more complex, suggesting that handedness and hemisphere dominance for speech are controlled by two genes with four alleles. Alleles L and l control which hemisphere is dominant for language, and alleles C and c decide whether hand control is contralateral or ipsilateral to this hemisphere. The model postulates, therefore, five sinistral and five dextral genotypes. Levy and Nagylaki (1972) attempted to test their model via predictions about recovery from lesions that cause aphasia and goodness of fit with proportions of hand preference in large-scale genetic surveys. Bryden (1982) stated that Levy and Nagylaki's theory fits the genetic survey results well but has the same difficulty as Annett in accounting for discordant handedness in twins.

Bryden (1982, 1987) himself suggested a different type of genetic theory, modeled on the work of Collins (1985). As does Collins, Bryden (1982, 1987) proposed that degree of laterality, not direction, is genetically controlled. At conception, the organism initially has a 50% probability of taking right or left shift in lateral preference. The right and left halves of the distribution of organisms consist of a majority of weakly lateralized individuals and a minority of strongly lateralized individuals. Borrowing from Corballis and Morgan's (1978) postulated left to right developmental gradient, the weak left individuals gradually shift over to the right side of the distribution, with postnatal environmental pressures converting, as it were, more of the weak-left individuals to a right side-orientation. A portion of the strongly left oriented individuals remain as left-handers. Bryden has gathered evidence in support of his theory by examining the absolute value of degree of laterality (in terms of relative hand performance) across generations in families. He found significant relations between degree of laterality within families and no relation between direction of preference in one generation to another. Bryden still described his theory as preliminary. Its importance lies less in its details (several objections to his "word picture," paraphrased above, occur to this writer) but in the delineation of another important factor related to handedness. Geschwind and Galaburda (1987) report some preliminary research evidence that suggests that weakly lateralized right-handers (as determined by a preference measure) resemble left-handers more than strong right-handers in many of the associations attributed to anomalous laterality.

A variation of the environmental position was expressed by Bakan (1972, 1977), who argues that left-handedness is the result of mild brain damage caused by hypoxia at birth. Bakan cited as evidence populations with higher than normal proportions of birth complications and left-handedness, including twins, stutterers, the mentally retarded, epileptics, and others. In addition, children of older mothers (fourth-borns and later) and first-borns were also reported to have a larger proportion of left-handedness due to the greater birth stress experienced under those circumstances. In a review, Nachshon and Denno (1987) found little corroboration for

Bakan's hypothesis. In Nachshon and Denno's study of 987 subjects on whom birth-stress data and laterality information were available, no significant correlation was found between hand preference and degree of birth stress.

The performance associations of dextrality and sinistrality indicate that sinistrals may be less lateralized than dextrals in many different kinds of tasks (Hicks & Kinsbourne, 1978). The lesser degree of lateralization in sinistrals seems to find confirmation in the fact that there are proportionately fewer extreme scores among sinistrals on handedness inventories (Corballis, 1983; Bradshaw & Nettleton, 1983). Kilshaw and Annett (1983) found that sinistrals show smaller skill differences between hands than dextrals. Other associations with sinistrality are learning disability, certain forms of immune disorder, and migraine. Certain exceptional talents relating to artistic ability, spatial abilities associated with architecture, and mathematics may also be associated with sinistrality (Herron, 1980; Geschwind & Galaburda, 1985a; Springer & Deutsch, 1985; Geschwind & Behan, 1982).

Gender may or may not have an association with handedness. A higher frequency of sinistrality is reported in males in some studies, but not all (Oldfield, 1971; Geschwind & Galaburda, 1985a). Males and females are thought to differ on the average in patterns of abilities (McGlone, 1980; Maccoby & Jacklin, 1974; Wittig & Petersen, 1979; Benbow & Stanley, 1980). McGlone's review suggests that the male brain is more asymmetrically organized for verbal and nonverbal functions, a finding that seems to have a structural/anatomical parallel in rats (Diamond, 1984, 1987).

The Assessment of Handedness

The assessment of handedness is not as straightforward as one would think. There is research to indicate that writing hand itself is the poorest single discriminator of handedness (Bradshaw & Nettleton, 1983). The most easily used systematic method of determining handedness is the handedness inventory (Geschwind & Galaburda, 1985a), but it is flawed in that there may be other aspects of laterality (trunk, gross motor) that are missed. Some researchers argue that performance measures are the most desirable means of determining handedness (Bradshaw & Nettleton, 1983; Bryden, 1977). This method was used by Deuel and Moran (1980) to determine the handedness of children in their sample. A researcher is left with the choice of using one of several questionnaires if the use of behavioral observation is logistically difficult. Two of the most widely used are the Edinburgh Handedness Inventory (Oldfield, 1971) and the inventory developed by Annett (1970). Neither the EHI nor Annett's questionnaire has marked advantages over the other in terms of reliability and related statistical properties (McMeekan & Lishman, 1975). Bryden (1977) compared the Crovitz-Zener and EHI in terms of reliability and validity. Validity in the handedness inventory is defined by Bryden as correlation between the handedness score and familial (parental) handedness. Bryden used the five items found on both the Crovitz-Zener and the EHI to determine a test-retest reliability index of .85 for the short form of the EHI. On the basis of this research, Bryden considered the EHI to be both reliable and valid. McMeekan and Lishman (1975) made lower estimates of the reliability of the EHI on the basis of changes in strength of handedness as measured by the questionnaire across administrations. The estimate of a Pearson's r of .97 for handedness categories is not considered meaningful to the question of the stability of the actual LQ's (Laterality Quotients) generated by the EHI. The latter researchers do not specifically address the issue of the stability of the actual left/right categories. In view of the small number of items and lack of stability of intracategory scores on the EHI, it should not be regarded as yielding a true interval scale (McMeekan & Lishman, 1975).

Measurement of CT Scans

No two studies dealing with the relation between handedness and anatomical asymmetries in the brain have measured computerized tomograms the same way. Therefore, the influence of measuring method and other factors (e.g., model of scanner used) on the results obtained is not known. Chui and Damasio (1980) and LeMay (1977) are both explicit on the methods for measuring the scans, making comparison possible. McShane and colleagues (McShane & Willenbring, 1984; McShane, et al, 1984; McShane, 1983) used a technique only slightly different from that used by Chui and Damasio (1980). In the former, scans taken from Caucasians with negative histories for alcohol abuse were noted to contain proportions of asymmetry that were comparable to those found by LeMay (1977) (the role of handedness was not investigated, however).

LeMay (1977) measured the widths of the frontal and occipital portions of the hemispheres at a point approximately 5 mm from the ends of the hemispheres. Asymmetries of the cranial vault were measured with a template of circular lines 5 mm apart centered on two lines intersecting at a 90-degree angle. Two other lines were then drawn at 30-degree angles on either side of the vertical line overlying the midpoint anteriorly.

Other studies are noteworthy in their attempts to deal with the error factor inherent in the limits in the resolution of the CT scanning equipment itself and the inaccuracy of hand measurement. In a study examining the ventricular asymmetries in certain categories of mental disorder, Tsai, Nasrallah, and Jaccoby (1983) and Andreasen, Smith, Jacoby, Dennert, and Olsen (1982) defined a significant asymmetry as a function of the standard error of measurement (SEM). After calculating the coefficient of reliability between multiple trace measurements of the brains in the sample, these researchers defined an asymmetry as an SEM with a confidence level of $P < .01$. This definition of an asymmetry was employed to guard against the possibility that an arbitrarily chosen criterion (e.g., 1 mm.) might be less than typical measurement error.

Purpose

The above discussion of issues supports the need for further research into the relation between a functionally lateralized preference (handedness) and patterns of neuroanatomical symmetry/ asymmetry. In the present study, analyses were carried out to determine if different patterns and proportions of neuroanatomical asymmetry occur in groups that differ on the handedness variable (Hyp. 1). In addition, analyses were conducted to determine if right-handers with left-handed first-degree relatives differ as a group from right-handers lacking such a family history (Hyp. 2). An attempt was made to determine the impact of diagnosis (reason referred for CT scan) on neuroanatomical asymmetry in the sample. The proportions of left- and right-handedness in given diagnostic groupings were also examined. Finally, the impact of age and gender on the distribution of asymmetries was also explored.

Independent Variables

The independent variables examined in this study were:

1. Handedness: defined as a relatively stable preference for the use of one hand over the other across a majority of skilled tasks requiring a leading involvement of one hand. The category into which each respondent falls (left or right) was determined by questionnaire.

2. Family history of handedness is defined as the presence or absence of left-handed relatives. That is, a sibling or parent of the respondent had to have been reported to be left-handed for a positive history of left-handedness to be reported. If no siblings or parents were reported to be left-handed, the respondent was recorded as having a negative history for left-handedness.

For the purposes of this study, the variables of handedness and family history of handedness in right-handers were treated as one variable with three levels. This is justified in that family history was treated as a special case of right-handedness in terms of its relation to neuroanatomical asymmetry. Conversely, the family-history element in a right-hander with left-handed relatives was also considered to be a situation in which the presence of left-handed first-degree relatives could indicate an increased probability that the right-hander with left-handed relatives could have either the genotype and/or the type of cerebral organization in which hand preference is random and therefore has a greater probability of having a pattern of neuroanatomical asymmetry resembling that of a left-hander.

Hypotheses

In a sample of hospital patients who have received CT scans:

1. There is no relation between handedness as measured by the Edinburgh Handedness Inventory (Oldfield, 1971) and patterns of neuroanatomical asymmetry (or, right-handers and left-handers do not show different patterns of neuroanatomical asymmetry).

2. Family history of handedness (the handedness of first degree relatives of the subject) is not related to patterns of neuroanatomical asymmetry in the frontal and occipital lobes. In addition, right-handers with left-handed relatives do not constitute a group with patterns of neuroanatomical asymmetry that differ from right-handers that lack left-handed first degree relatives. Left-handers do not constitute a group that differs from right-handers who lack left-handed relatives.

CHAPTER III

METHODOLOGY

The purposes of this research were to investigate the role of (1) handedness as a marker for neuroanatomical asymmetry and (2) family history as a moderating variable or intervening factor in the relation between these variables. Studies cited in the previous chapter generally do not considered the family history variable (suggested by research on the genetic basis of handedness) and have examined the significance of frequencies of asymmetries without actually scrutinizing the statistical significance of the differences between the group measurements. To overcome these limitations, the current study employs multiple measurements of the CT slice and includes a family history element to differentiate the right-handed subjects into two categories.

Experimental Design

The independent variables examined in this study are: (1) Handedness: defined as a relatively stable preference for the use of one hand over the other across a majority of skilled tasks requiring a leading involvement of one hand. The category into which each respondent falls (left or right) was determined by questionnaire. (2) Family history of handedness was defined as the presence or absence of left-handed relatives. That is, a sibling or parent of the respondent had to have been reported to be left-handed for a positive history of left-handedness to be reported. If no siblings or parents were reported to be left-handed, the respondent was recorded as having a negative history for left-handedness. For the purposes of this study, handedness was treated as one variable with three levels. This was justified in that family history is being treated as a special case of right-handedness in terms of its relation to neuroanatomical asymmetry. The variables are further described below.

The major dependent variable, neuroanatomical asymmetry, is defined in various mathematical expressions of the left-right differences between the cerebral hemispheres represented in the CT scan slice measured. This variable was examined in both continuous and categorical forms. Originally, all the brain scan series used in this study were to be measured on the computer console attached to the CT scanner at Logan Regional Hospital. Images of the scans stored on computer disks were displayed on the console screen and measured by the investigator with a light pen and the console software. Due to a major loss of data from the magnetic media (computer disks) and lack of backup for these media, it was decided that tracings made from films of the same scans (measured for a parallel study) would be used to substitute in whole or in part for the missing data. A total of 108 traced scans and 69 console measured scans were available for use in the study. Between the trace and console data sets, 58 subjects were common to both. In the remainder of this chapter and in the chapter that discusses results, the handedness groups are referred to in abbreviated form (Rh=right-hand, Rhl=right-handed with left-handed relatives, and Lh=left-handed) and (t) and (c) immediately after the abbreviation of the handedness group refer to trace and console measures, respectively.

Subjects

This study involved a subgroup of a larger study of approximately 500 individuals who received CT scans at Logan Regional Hospital (McShane, study in progress) who responded to handedness questionnaires. Less than a third of those contacted responded to the questionnaires or direct phone contacts by the author. The impact of this low response rate on the characteristics of the sample is not certain. It is likely that those who responded were on the average more healthy and motivated than the nonrespondents. This subgroup consisted of 68 females and 40 males referred for computerized tomography. The gender disparity was greatest in the Lh(t) group with 2 males and 14 females. The Rhl(t) subset contains 14 females and 10 males, and the Rh(t) subjects consists of 39 females and 29 males. The significance and impact of this disparity on the analysis is examined below and in subsequent chapters.

The ages of the subjects are of theoretical importance to the study of neuroanatomical asymmetry. The Rh(t) group was older than the other two groups, and all groups contained a very wide age range weighted toward late middle aged and elderly subjects (see Table 2). Subjects were categorized into young (low through 23), middle (24 through 40), and older (41 through high) age groups. The frequencies of age categories for handedness groups were tested by chi-square. The coefficients for the trace and console groups approached but did not reach the α level of .05 ($p = .10370$ for console, $p = .08332$ for trace). However, in practical terms, the older age groups can probably be considered to be somewhat overrepresented in the

Table 2

Mean Ages and Descriptive Statistics of Ages by Handedness and Family History Groups, Trace and Console Data

Group number(n)	Mean	SD	SE	Min.	Max	Range
Trace						
All (108)	45.780	20.935	2.005	4.000	81.000	77.000
Rh (68)	49.279	20.890	2.533	5.000	79.000	74.000
Rhl (24)	39.333	19.455	3.971	4.000	78.000	74.000
Lh (16)	38.875	20.093	5.023	7.000	81.000	74.000
Console						
All (69)	44.797	20.189	2.430	4.000	78.000	74.000
Rh (49)	48.204	20.070	2.867	5.000	78.000	73.000
Rhl (14)	39.857	19.771	5.284	4.000	69.000	65.000
Lh (6)	38.875	20.093	5.023	7.000	81.000	74.000

sample, most notably in the Rh(t) group.

The CT images measured in this project were judged by a certified CT technician to be relatively free of significant distorting pathology. Subjects were questioned about the reasons they were referred for a CT scan and whether findings were reported to them (i.e., positive or negative findings), and a rough categorizations were made of the reasons for referral (e.g., headache, stroke, head trauma). This information was gathered to assess any variation of referral reason with handedness category (see Table 3). Chi-square tests of handedness × referral question category were carried out for the trace and console data sets, and the results were not significant (trace, p= .73156, console p= .52036). Subjects were also questioned as to whether they drank alcoholic beverages. No attempt was made to differentiate extent of use and/or abuse (although a small number of

Table 3

Frequencies and Percentages of Referral Question Categories for the Traced Subjects and Handedness Categories (number/percent)

Referral question Category	All Trace	Rh Trace	Rhl Trace	Lh Trace
Headache	35/32.1	20/29.4	9/37.5	6/37.5
Stroke	16/14.7	11/16.2	2/8.3	3/25.0
Head trauma	12/11.0/	10/14.7	1/4.2	1/5.9
Dizzy, loss of balance, musc. control	8/7.3	5/7.4	3/12.5	0
Seizure disorder	7/6.4	5/7.4	1/4.2	1/6.3
Memory loss	3/2.8	3/4.4	0	0
Intra cranial Pressure	1/0.9	1/1.5	0	0
Dementia	3/2.8	2/2.9	1/4.2	0
Other	14/12.8	7/10.3	3/12.5	4/25.0
Missing data	9/8.3	4/5.9	4/16.7	1/6.3

Console subjects and handedness categories (number/percent)

Referral question Category	All Console	Rh Console	Rhl Console	Lh Console
Headache	21/30.4	12/24.5	7/50.0	2/33.3
Stroke	7/10.1	6/12.2	0	1/16.7
Head trauma	10/14.5	8/16.3	1/7.1	1/16.7
Dizzy, loss of balance, musc. control	9/13.0	6/12.2	3/21.4	0
Seizure disorder	5/7.2	4/8.2	1/7.1	0
Memory loss	3/4.3	3/6.1	0	0
Intra cranial Pressure	2/2.9	2/4.1	0	0
Dementia	0	0	0	0
Other	7/10.1	5/10.2	0	2/33.3
Missing data	.5/7.2	3/6.1	2/14.3	0

subjects reported past heavy use). In all, 21 (18.9%) reported drinking alcohol and 79 (71.2%) denied use. Data were missing for 10 subjects (9%). As noted in the literature review, a history of alcohol abuse might be associated with a greater degree of symmetry between the cerebral hemispheres (McShane & Willenbring, 1984) and as such could function as a moderator variable. Chi-square tests carried out to determine if alcohol use was nonrandomly distributed across the handedness groups revealed no significant departure from chance (console, p= .5203, trace p= .4183). CT findings (whether or not the subject had been told of actual CT findings by the doctor) were positive (that is, the subject had been told of findings from the scan) for 12 (17.4%) subjects, negative in 51 (73.9%) subjects and not available for 6 (8.7%) of the console subjects from whom supplemental questionnaire data were not available. For trace subjects, the response to the CT-finding question was positive for 21 (18.9%) of the subjects, negative for 79 (71.2%), and no data was available for 10 subjects, from whom the supplemental questionnaire data were not available. Chi-square tests of the distribution of CT-finding categories across handedness categories revealed no significant departure from random distribution (p= .3201 for console, p= .2552 for trace). The percentages of alcohol use and CT finding responses are listed in Table 4.

Table 4

Frequency and Values for the Whole Sample and Groups on Alcohol Use and CT Finding (number/percent of category)

	Alcohol used?			Positive CT finding?		
All	#Yes	#No	#No data	#Yes	#No	#No data
Trace						
→	21/19.4	77/71.3	10/9.2	20/18.5	78/72.2	10/9.0
Rh(t)	15/22.1	48/70.6	5/7.4	15/22.1	49/72.1	4/5.9
Rhl(t)	2/8.3	18/75.0	4/16.7	2/8.3	17/70.8	5/20.8
Lh(t)	4/25.0	11/68.0	1/6.3	3/18.8	12/75.0	1/6.3

Console (number/percent of category)

	Alcohol used?			Positive CT finding?		
All	#Yes	#No	#No data	#Yes	#No	#No data
Console						
→	16/23.2	48/69.6	5/7.2	12/17.4	51/73.9	6/8.7
Rh(c)	12/24.5	34/69.4	3/6.1	10/20.4	36/73.5	3/6.1
Rhl(c)	2/14.3	10/71.4	2/14.3	1/7.1	10/71.4	3/21.4
Lh(c)	2/33.3	4/66.7	0	1/16.7	5/83.3	0

Finally, according to 1980 census data, the counties served by the hospital from which the patient population was drawn are 96% Caucasian and predominantly Mormon and northern European in descent. The remaining 4% of the population consists of Hispanics, Blacks, and other minorities. No ethnic minorities were present in the sample.

Questionnaire data were available identifying 68 right-handers, 16 left-handers, and 24 right-handers with left-handed relatives. The sample of 68 females and 42 males. In a breakdown of gender by group, the right-handed subjects were 39 females and 29 males, the right-handed with left-handed relatives subjects were 14 females and

10 males, and the left-handed group included 2 males and 14 females. Chi-square tests were performed to evaluate the degree to which the within-group disparity of sex distribution departed from chance. The chi-square coefficient approached but did not surpass the α level of .05 with a p= .07509 (console, p= .08713) in the trace data set (console, p= .08713). This suggests that the distribution of males and females across handedness categories does not differ significantly from chance. However, this would appear to be a situation in which the practical significance of the small number of males in Lh(t) cannot be overlooked. The results of this study with respect to any asymmetries and characteristics of the brains in Lh(t) cannot be applied with confidence to male left-handers.

Assessment of Handedness

Subjects were mailed a short form of the Edinburgh Handedness Inventory (Oldfield, 1971) as revised by Bryden (1977) with additional questions to determine the handedness of first-degree relatives. Parents of children too young to complete the inventory were asked to watch their children carry out the inventoried activities and fill in the questionnaire. Subjects who did not respond were telephoned, asked if they would fill out the questionnaire, and mailed a second instrument. Holdouts after the second mailing were called by the investigator and interviewed by phone.

The EHI consists of a list of five activities followed by two adjacent response areas, a LEFT and a RIGHT response column (Appendix B). The subject is instructed to show his or her preference in the use of hands for particular activities by placing a plus (+) in the column under LEFT or RIGHT as appropriate. If the hand preference is very strong for a particular activity, the subject is instructed to endorse the hand preference with two +'s, and activities preformed with equal frequency with either hand are endorsed with a + in both LEFT and RIGHT columns. Scoring involves adding up the number of +'s in each column and then subtracting the number of +'s under LEFT from the number under RIGHT. The result is then divided by the total number of +'s and multiplied by 100 to yield a laterality quotient (LQ) between zero and -1.00 to indicate a left-hand preference and scores between zero and +1.00 to indicate right-hand preference.

The questionnaires returned by the subjects contained a large number of responses to the questions dealing with hand preference. A typical response consisted of a single + in the RIGHT column for the first activity, followed by the same response for all remaining preference questions, with no +'s in the left-hand column. On other questionnaires, a column of double +'s was found under the RIGHT column, accompanied by a column of single pluses under the LEFT. Other responses (for instance, from left-handers) were double +'s in the LEFT under specific activities (such as Writing and Using Scissors) and three other activities were endorsed with single +'s under the RIGHT column. This response would have the majority of +'s in the LEFT column and was closer to how the questionnaire was meant to be answered. Yet another type of response consisted of a single + in the first activity in the right-hand column, followed by a line drawn down through all the other spaces in the RIGHT column.

This was interpreted to mean a right-hand preference. In the cases noted above and in similar instances, subjects were assigned to the left and right categories on a basis of simple majority of responses in a given column. Family history of handedness was a subcategory into which a subject was placed when a parent or sibling was indicated as having a left-hand preference. In many cases it was assumed that the family member might not be available to take the EHI. Therefore, family history was established by the respondent's report alone. In the event that a subject indicated no knowledge of family history (e.g., respondent was adopted) and the subject was right-handed, that subject was allocated to the right-handed group, as this was the higher probability of history. This lowered certainty of family history for some of the subjects might tend to moderate or alter the relation between right-handedness and the asymmetry variables. Another factor that might lower the reliability of family history, especially in older subjects, might be that their parents, siblings, etc. were more likely to have been encouraged or pressured to use their right hands over their left. This might also serve as a moderator variable, reducing the putative relation that is being examined here.

Measurement of CT Scans

The following describes the technique used to measure CT scans on the CT computer console. The measurement method described below corresponds closely to the method used to measure the tracings. Certain differences between the techniques may account for the relatively low similarity between the console and trace data.

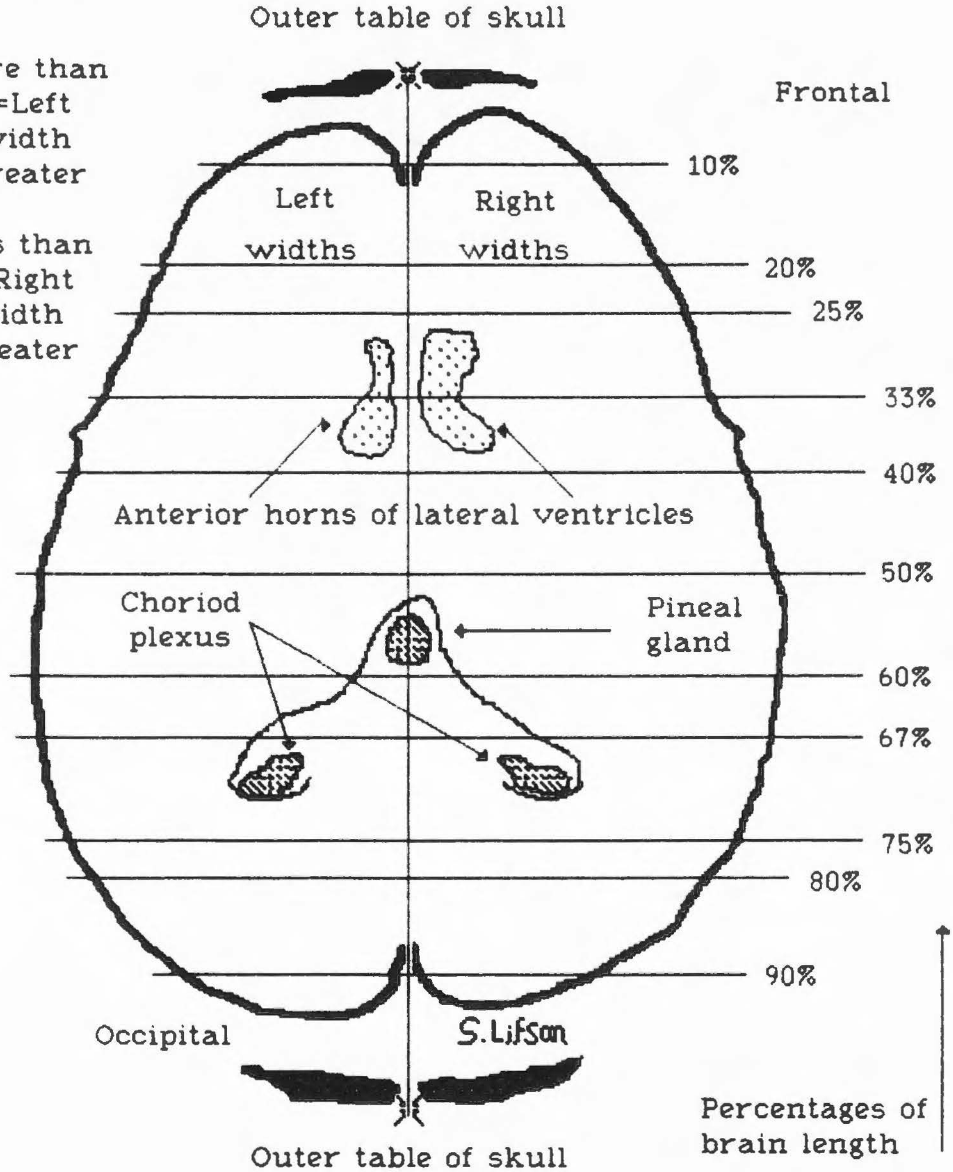
The section viewed on the tomograms is an axial view at zero angulation cutting through the frontal lobes anteriorly and the occipital lobes posteriorly. The pineal body and the frontal and posterior horns of the lateral ventricles are major landmarks at this level. While the section is portrayed on the scanner's screen, a point is marked with a light pen on the outer table of the skull directly above the notch indicating the interhemispheric fissure and directly below the posterior notch formed by the fissure, again on the skull's outer table. The computer then generates the anterior-posterior (AP) line and gives its length in millimeters. This line is entered on the coding sheet rounded to the nearest whole millimeter. The examiner then marks off perpendicular slices of the brain in percentages of the AP line. The endpoints of the perpendicular lines are the edges of the brain section at points perpendicular to the AP line. The computer gives right and left line segments from the AP line in millimeters as well as the total width of the cut. Measurements of the brain's right and left width are taken at 90, 80, 75, 67, 60, 50, 40, 33, 25, 20, and 10% of the AP line. Percentages 90 through 67 are considered to correspond to the occipital lobes, 67 through 33 to the temporal-parietal region, and 33 through 10 % to the frontal lobes. The measurement points in terms of percentages of the AP line are illustrated in Figure 1. The percentages are on the right of the figure, and the derived ratios and differences are described on the left and below. The AP line divides the width measure (the line space within the boundaries of the slice) into right and left halves, and the left half was divided by the right half to yield the ratios. These ratios where also averaged by region and hemisphere to permit analyses at a number of different levels. The analyses were carried out at the ratio level (a transformed score) to control for magnitude differences between the console and scan measurements of the subject's brain. Analyses were also carried out with direct comparison of right-side measures, left-side measures, and differences obtained in subtracting left from right. These analyses illustrate different aspects of the forms taken by the asymmetries. Figures 2-4 illustrate in schematic fashion a number of the structures passed through on the level of the CT scan. Table 5 lists these and additional structures and areas and their relative position on the AP line. It should be noted that individual brains are quite variable, and no claim is made that these figures and lists of structures account for the position of these features on every brain.

Ratio=
Left÷Right

1=Equal
widths

More than
1=Left
width
greater

Less than
1=Right
width
greater



Difference =Left- Right	0=Equal widths	+ diff=Left width greater	- diff=Right width greater

Figure 1. Axial view of CT section of brain.

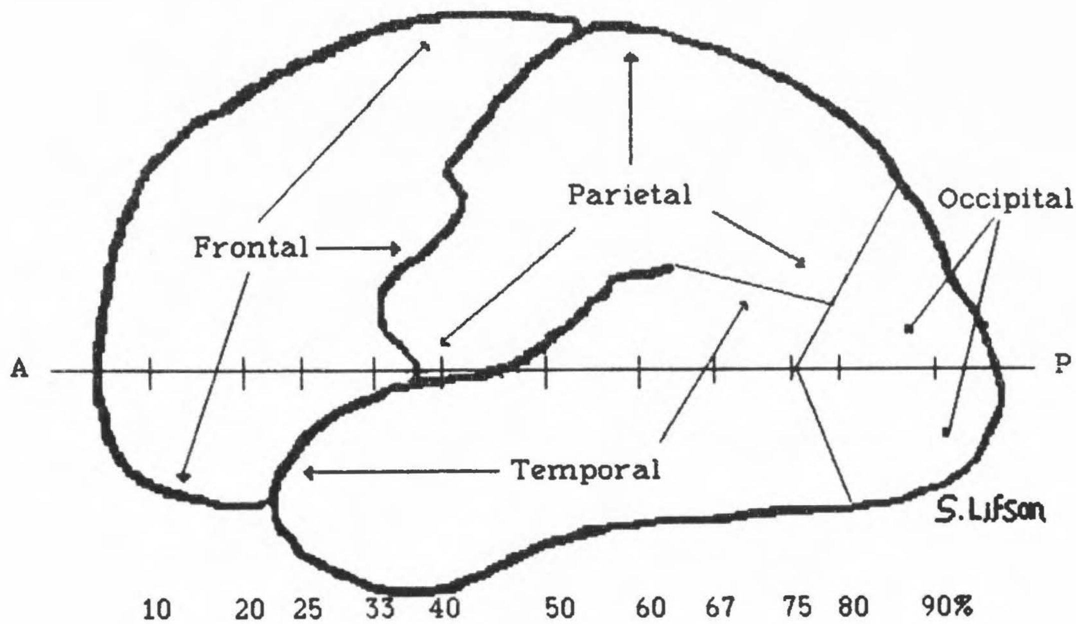


Figure 2. Lobes of the brain in lateral view.

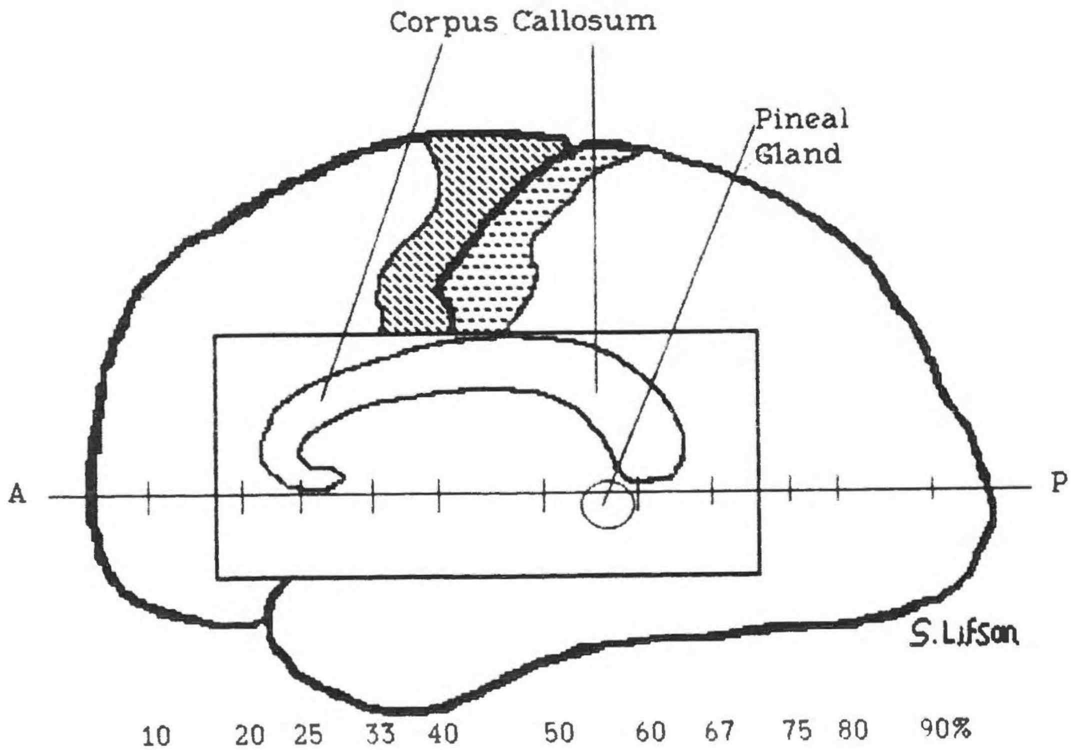


Figure 3. Lateral cutaway view of internal landmarks in the brain relative to anterior-posterior line and level of scan.

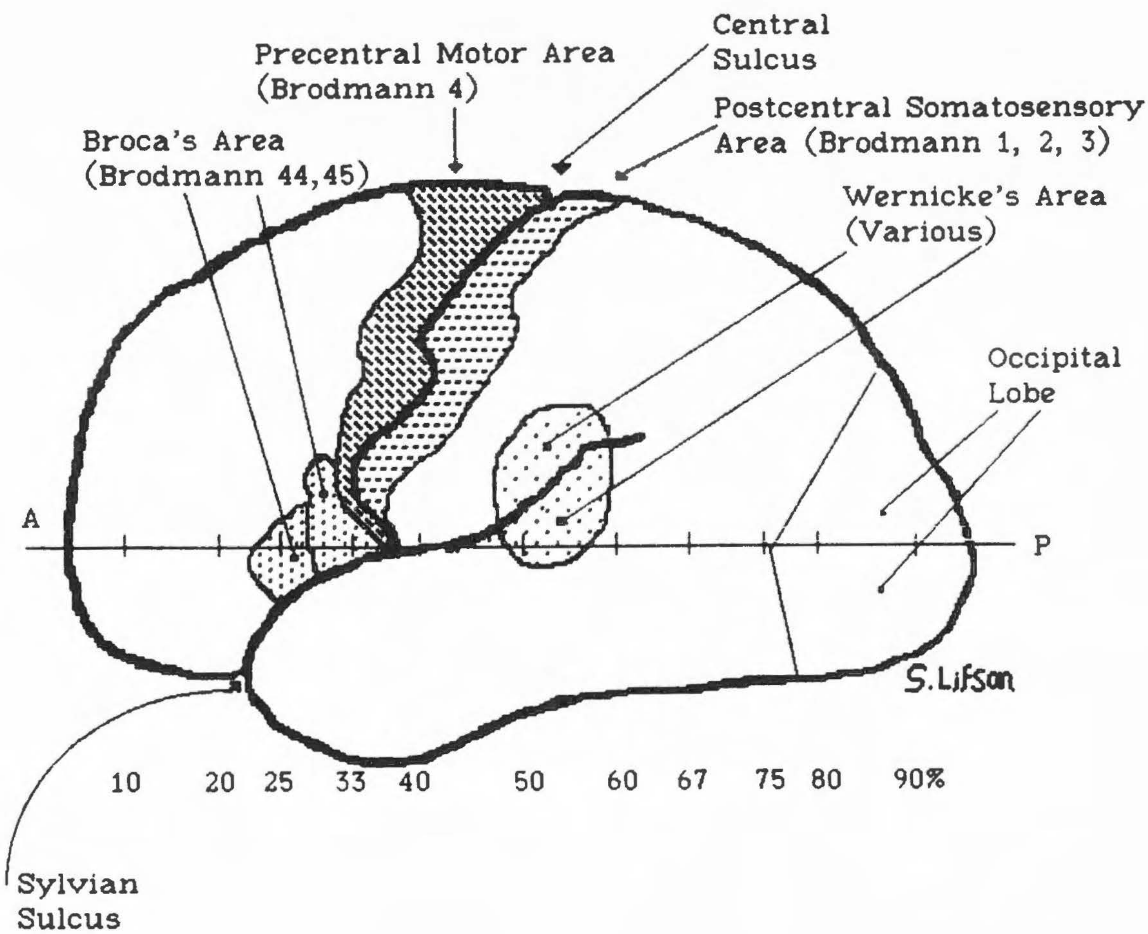


Figure 4. Lateral view of the brain showing selected functional cytoarchitectonic areas.

Table 5

Structures on the Level of the CT Scan and Their Approximate Position on the Anterior-Posterior Line

	Approximate Location(%AP)
Gross brain divisions, 90% to 10% of AP	
1. Occipital lobe	90 - 75%
2. Temporal lobe (Possibly lowest of parietal lobe)	75 - 33%
3. Frontal lobe	33 - 10%
Surface features on/near path of CT scan level, 90% to 10%	
1. Calcarine Sulcus	90%
2. Parieto-occipital Sulcus	90%
3. Lower margin of Angular Gyrus	80%
4. Lower margin of Supramarginal Gyrus	67%
5. Superior Temporal Sulcus (Lower middle) /Upper part of Middle Temporal Gyrus	67 - 33%
6. Lower portion of Inferior Frontal Gyrus	25%
Lateral surface cytoarchitectonic areas (90% to 10%)	
1. Area 17, Primary visual receptive cortex	90%
2. Area 18-19, Primary visual association cortex	90 - 75%
3. Area 37, Visuo-auditory association cortex	75 - 67%
4. Area 21, Auditory association cortex	67 - 60%
5. Area 22, Auditory association cortex including part of Wernickes Area	60 - 50%
6. Area 42, Primary auditory receptive area (Heschl's Gyrus)	50 - 33%
7. Areas 44/45, Broca's area	33 - 25%
8. Area 12 and 10, part of prefrontal cortex	10%

The research design was presented to the Human Rights Committees of Logan Regional Hospital and Utah State University before the survey instrument was mailed. A consent form was enclosed with the questionnaire and cover letter (see appendices) and permitted the subject to choose his/her level of involvement (or noninvolvement) with this study and other studies served by the same questionnaire. The identity of the subjects was protected by keeping address lists, completed questionnaires and other materials in locked files with the key kept by the principle investigator.

CHAPTER IV

RESULTS

The primary purposes of this study were to investigate the associations between (1) handedness and neuroanatomical asymmetry and (2) familial history of handedness as a moderating or intervening factor in the relation between handedness and neuroanatomical asymmetry. The literature suggests that right-handedness is more strongly associated with certain gross anatomical asymmetry patterns than left-handedness. The literature also suggests that handedness may be related to a number of factors, notably a right-shift factor that is present in most right-handers and absent in most left-handers and a subset of right-handers. In the latter group, hand preference is more likely random and subject to postnatal environmental factors. Therefore, family history (left-handed first-degree relatives) may be related to the frequency and extent of neuroanatomical asymmetry in a subset of right-handers.

Description of the Sample

In the course of this study console measurements were made by the author, who was blind to the handedness and family history of the subjects, but not to the hypotheses. Later, when the loss of data was discovered, trace data were used to supplement and replace them. These data had been collected by individuals blind to the hypotheses of the study. Questionnaire data were collected by mail and later by telephone follow-up by the author. The measurement data were analyzed in terms of ratios between left and right measurements (left side÷right side=ratio), mean comparisons of the untransformed raw scores (AP, total brain widths, and left and right sides), difference scores derived by subtracting left-side from the corresponding right-side measures (left-right=difference), and categorical data. These comparisons were carried out between console and trace data sets and within the sets broken down into the three handedness/familial history groups. The answers to the questionnaire concerning referral (elicited from the subjects and/or their families to specify problem that had led to referral for medical evaluation and subsequent CT scan), alcohol use (a yes/no question to determine whether alcoholic beverages were imbibed by the subject), patient knowledge of CT finding (whether the subject had been told of CT findings by the doctor—a highly reactive question of doubtful use), and gender were examined in terms of frequencies per measurement method (trace, console) and handedness group. The statistical characteristics of these variables are reported in the method chapter.

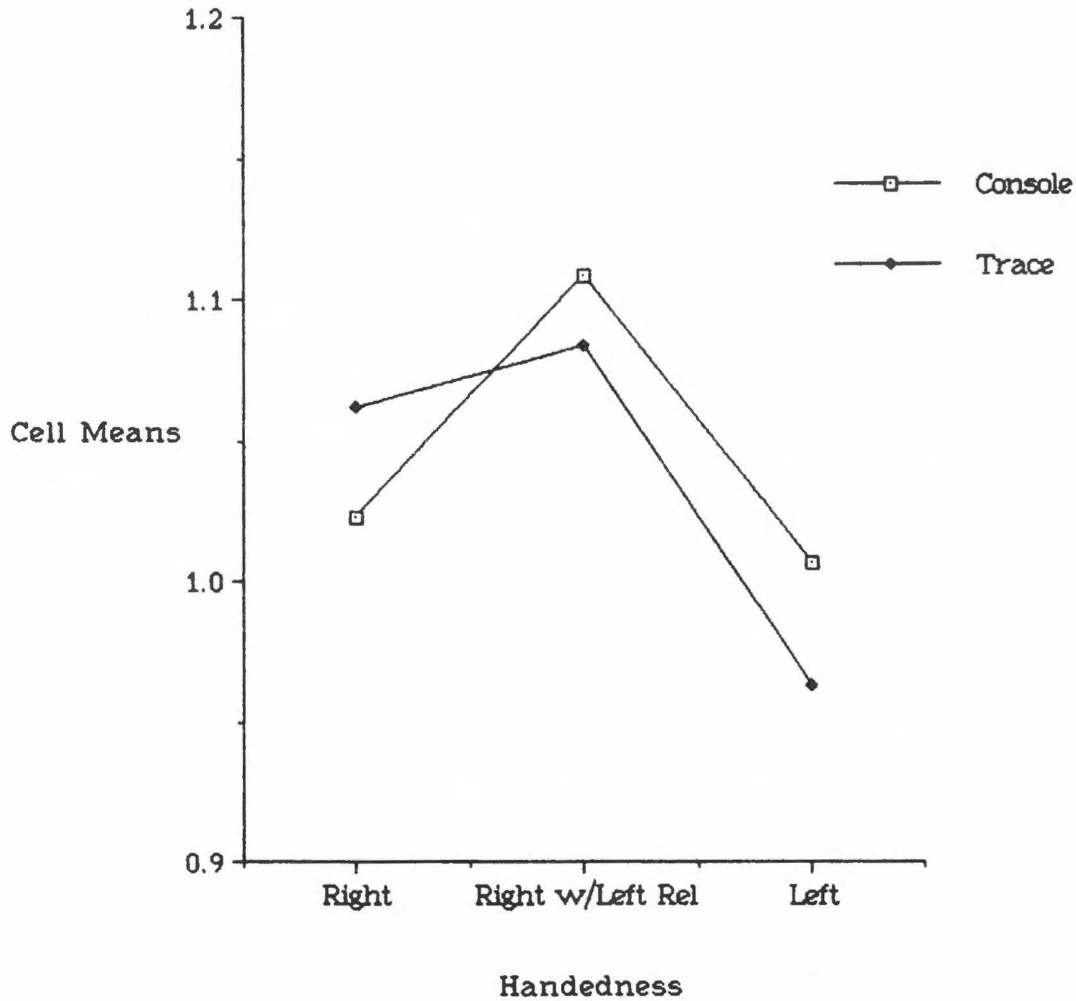
Differences Between Trace and Console Data

Table E1 in the Appendix presents a summary of measurement data for the entire sample and by handedness group for each method. There are statistical differences between the trace and console data sets on the measurements that were duplicated (n=58) when these measures were broken down by handedness group. These differences were not apparent in the untransformed data (whole and left/right widths) or in the ratios and difference scores until they were analyzed in a Measurement Method × Handedness group fashion. The differences are greatest in several of the occipital measures of the right-handed group. For the 38 right-handed subjects on whom both trace and console measures were available, difference measures for tracings were of greater magnitude than corresponding console measurements. Not all these differences are significant. However, an opposite pattern is observed in the right-handers with left-handed relatives group. Again focusing on the occipital area, the subjects on whom trace and console data were available tended to have larger difference scores in the console group, as opposed to the right-handers who tended to have larger difference scores in their trace measurements.

To summarize at this point, a certain number of measurements of theoretical importance to this study tend to be higher or lower in particular handedness groups depending on the measurement method used. Console-measured right-handers had at times significantly smaller measures (at 90%, 80%, and 75% of AP) in the occipital area than corresponding trace-measured subjects. Console-measured Rhl subjects had difference scores of greater magnitude in the occipital area (more than 1 mm difference at 90% and 80% of AP and .50 mm at 75% and 67%, respectively). Although the console Rhl measures are not in and of themselves significantly different from the trace measures of the same subjects, it was suspected that these differences (and similar ones in the six left-handed subjects on whom trace and console measures were available) could have played a role in the different findings obtained when one-way ANOVA was carried out for Handedness × Asymmetries.

To further investigate this possible interaction between handedness and measurement method, a repeated-measures design analysis of variance was carried out. Repeated-measures ANOVA's were conducted for ratios of the left-right measurements at each percentage of AP. In other words, the 58 subjects on whom trace and console measurements were available were broken down into handedness categories, and the expected and actual error variances were compared. Ratios were used to specifically control for the possibility that the difference scores between left and right had been influenced by extraneous factors (e.g., the difference in size resulting from the position of the projector from the wall versus the actual size reported by the computer in the console measures). There was no significant effect found for measurement method. However, right-handed subjects were found to have significant Hand × Measurement interactions at the 80% and 75% levels. Console-measured Rh subjects were significantly smaller than trace-measured Rh subjects at both of the above percentages of the AP line. Figures 5 and 6 illustrate this interaction graphically. Table 6 illustrates the differences between the handedness groups by Method × Handedness in the 58 subjects on whom trace and console data is available.

Only speculation can be offered as to why the two measurement methods yielded such different results. One possibility concerns the fact that the light pen on the CT console was not ideally situated for a left-handed user (the author). The point of light on the CRT screen was also wont to dance wildly, making placement difficult. Another factor that could account for the more marked differences between left- and right-hemisphere widths between methods (whole widths



<u>Figure 5</u>. Cell means of the measurement method by handedness group (80% AP).

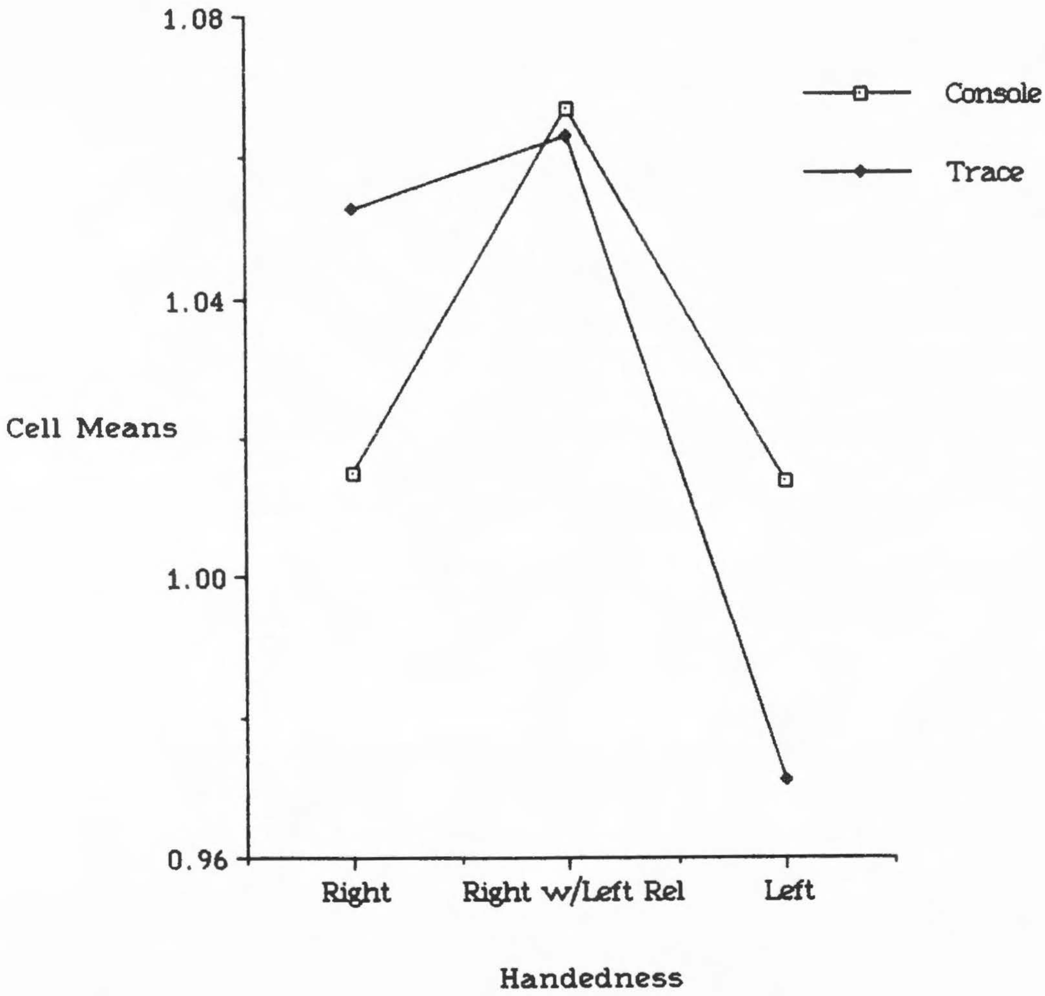


Figure 6. Cell means of the measurement method by handedness group (75% AP).

Table 6

T-Test Comparisons of Trace and Console Data Sorted by Handedness Groups

Handedness group: right-hand

Variable L-R dif scores	#of cases	Mean	SD	Dif. mean	t value	P=
T(race)90	38	2.9737	6.399	2.0526	2.27	.029
C(onsole)90		.9211	4.670			
T80	38	2.4211	5.330	1.4737	1.98	.055
C80		.9474	3.883			
T75	38	2.5000	4.196	1.7632	2.57	.014
C75		.7368	3.703			
T67	38	.6316	4.499	.5789	.82	.415
C67		.0526	2.780			
T60	38	-.1579	4.010	.0000	.00	1.000
C60		-.1579	2.444			
T50	38	-.5000	2.689	.0789	.15	.878
C50		-.5789	2.213			
T40	38	.0000	3.247	.7368	1.13	.264
C40		-.7368	2.668			
T33	38	.4474	3.285	1.3158	2.24	.031
C33		-.8684	2.095			
T25	38	-.8158	5.382	.3421	.43	.668
C25		-1.3947	2.236			
T20	38	-1.2368	2.963	.1579	.32	.747
C20		-1.3947	2.388			
T10	38	-2.5000	5.451	.4211	.49	.626
C10		-2.9211	3.672			

(table continues)

Table 6

T-Test Comparisons of Trace and Console Data Sorted by Handedness Groups (Table continued)

Handedness group: right-hand w/left relatives

Variable L-R dif scores	#of Cases	Mean	SD	Dif. mean	t value	P=
T(race)90	14	3.9286	6.662	-1.1429	-.60	.556
C(onsole)90		5.0714	3.293			
T80	14	3.6429	3.543	-1.5000	-1.32	.208
C80		5.1429	3.325			
T75	14	3.0714	3.912	-.5000	-.52	.613
C75		3.5714	3.031			
T67	14	.7143	3.049	.5000	-.52	.609
C67		.2143	1.847			
T60	14	-.4286	2.102	-.4286	-.59	.568
C60		.0000	1.922			
T50	14	-1.6429	2.706	-.2143	-.28	.787
C50		-1.4286	2.533			
T40	14	-1.2857	2.998	.5000	.61	.554
C40		-1.7857	2.940			
T33	14	-1.5000	3.568	.5714	.74	.470
C33		-2.0714	2.702			
T25	14	-1.9286	3.293	-.2857	-.53	.605
C25		-1.6429	2.234			
T20	14	-1.4286	3.610	1.2857	1.16	.266
C20		-2.7143	2.234			
T10	14	-2.6429	5.597	1.3571	.81	.431
C10		-4.0000	3.162			

(table continues)

Table 6

T-Test Comparisons of Trace and Console Data Sorted by Handedness Groups (Table continued)

Handedness group: left-hand Variable L-R dif scores	#of cases	Mean	SD	Dif. mean	t value	P=
T(race)90	6	-.5000	6.834	-.6667	-.39	.715
C(onsole)90		.1667	5.672			
T80	6	-2.1667	5.742	-2.3333	-1.17	.295
C80		.1667	3.061			
T75	6	-2.0000	6.066	-2.5000	-1.36	.232
C75		.5000	3.728			
T67	6	-3.0000	3.742	-2.3333	-2.09	.091
C67		-.6667	1.966			
T60	6	-4.1667	3.371	-2.1667	-1.73	.143
C60		-2.0000	1.414			
T50	6	-3.8333	2.787	-2.1667	-1.90	.115
C50		-1.6667	1.366			
T40	6	-2.1667	1.194	-1.3333	-1.35	.235
C40		-.8333	1.722			
T33	6	-2.1667	2.317	-1.0000	-1.17	.296
C33		-1.1667	1.941			
T25	6	-1.5000	3.271	-.8333	-.96	.383
C25		-.6667	1.633			
T20	6	-2.1667	2.137	-.5000	-.47	.656
C20		-1.6667	2.251			
T10	6	.1667	4.792	.1667	.09	.929
C10		.0000	1.095			

and lengths were more similar) lies in the console software. The AP line generated by the console automatically disappeared when the next line (the measure of width) was made. The need to estimate the appropriate point of division between the left and right hemisphere without the AP line could account for the disparity between left/right hemisphere measures and differences across methods. The stability of reference points in the trace data recommends it as more accurate, reliable, and true to the object being measured.

Mean Differences Between Handedness Groups

One-way ANOVA's were computed between handedness categories (Rh, Rhl, Lh) and the measures taken at all eleven percentage points of the AP line. As mentioned above, the ANOVA's were carried out by Left sides (90% to 10%) × Handedness, Right sides (90% to 10%) × Handedness, Left÷Right (L÷R) × Handedness, and Left-Right difference scores × Handedness. Where feasible, these analyses were carried out for both trace and console data. In a later section, analyses dealing with possible confounds (gender and age) will be discussed.

Left and Right Sides by Hand

No significant between-group differences in left-hemisphere widths were seen in the trace data for the handedness groups (Figure 7). Significant differences were seen in console data between mean left hemisphere widths at the 90% and 80% points (Figure 8). Specifically, the Rh(c) left-side width was significantly smaller than the corresponding side in Rhl(c). This difference between console and

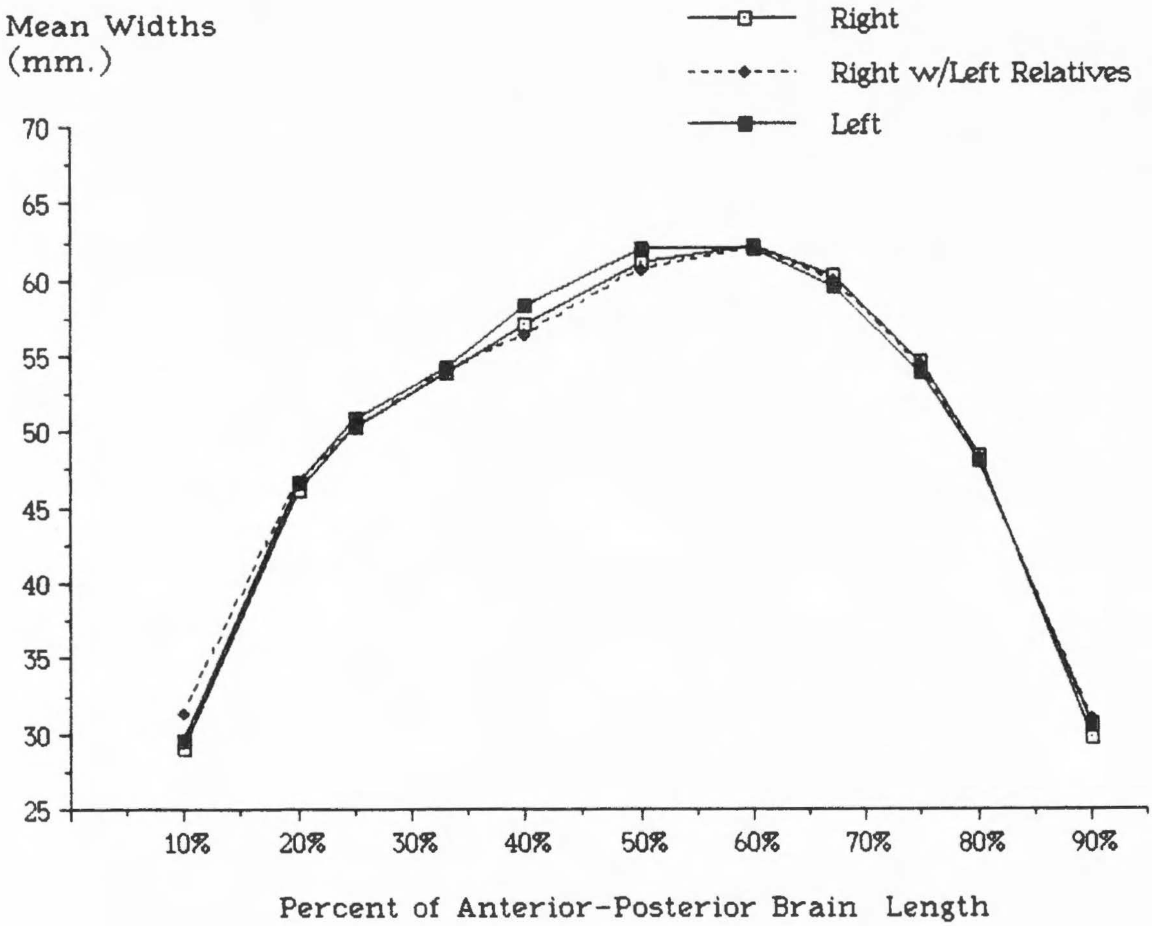


Figure 7. Trace left-hemisphere widths by handedness group.

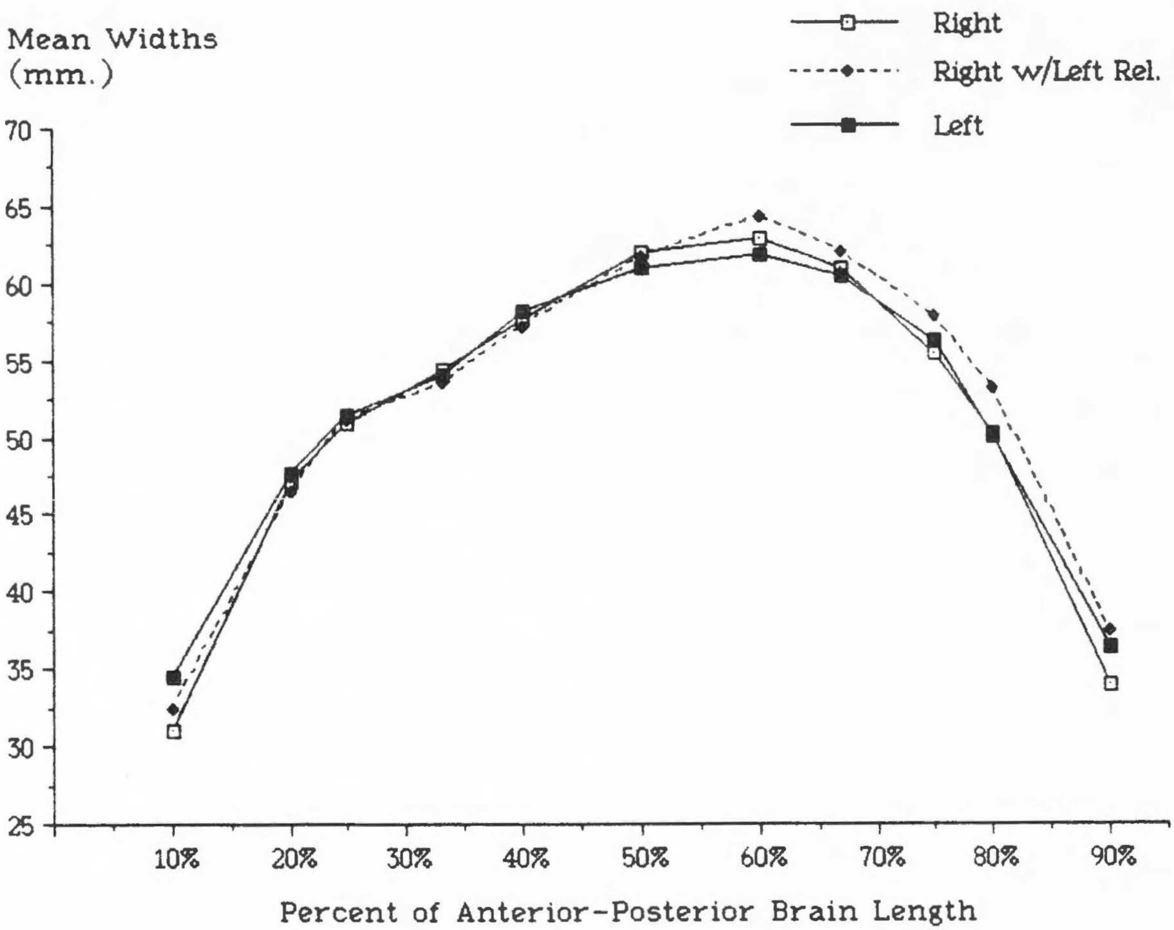


Figure 8. Console left-hemisphere widths by handedness group.

trace results will be discussed in the light of the differences between the trace and console data noted in the previous section.

Again examining trace data, significant differences in right-hemisphere widths by handedness group were noted at the 80% (OC2), 75% (OC3), and 60% (TP2) of AP points. At the 80% and 75% level of measure, the right-hemisphere widths of the Rh(t) and Rhl(t) subjects were significantly different from the Lh(t) subjects, differentiated by a least significant difference procedure. At the 60% of AP level, only Rh(t) was significantly distinguished from Lh(t), with Rhl(t) lying midway between them in magnitude. The ANOVA for the fourth measurement in the occipital/temporal/parietal area (OC4) at 67% of AP approached but did not meet the $\alpha = .05$ criteria for significance (actual $p = .0548$) (See Figure 8, above).

No significant differences were observed between right-hemisphere widths by handedness group in the console data (See Figure 9).

To summarize at this point, the trace data left-hemisphere widths by handedness group ANOVA's revealed no statistically significant differences between hemisphere widths by handedness group at any measurement point on the AP. The right-side widths did vary by handedness group at two of the occipital region measurement points (OC2 at 80%, $p = .0327$, and OC3 at 75%, $p = .0119$) and at the temporal/parietal (TP2) point (60%, $p = .0292$). None of the other measures in the temporal/parietal or frontal areas attained significance. The picture presented by the trace data is of a left hemisphere that does not show significant variability by handedness. The right hemisphere does appear to have greater variability

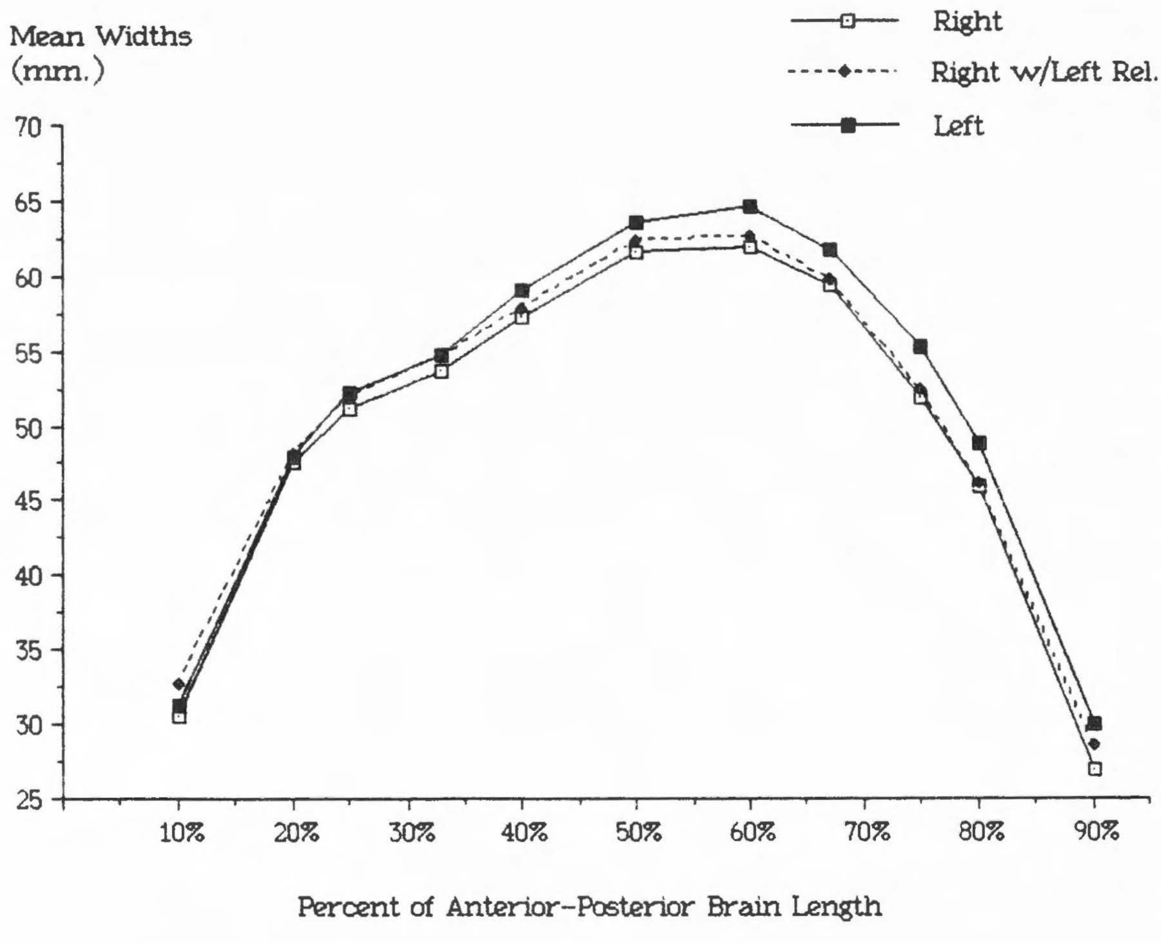


Figure 9. Trace right-hemisphere widths by handedness group.

associated with handedness, principally in the posterior quadrant. In that area, three of five of the percentage points showed significant between group differences. In all three cases, Lh(t) had a greater width than Rh(t), and in 2 of 3 right hemisphere widths Lh(t) was of significantly greater magnitude than Rhl(t) as well. In no case was Rhl(t) significantly different from Rh(t). Console data did not show the same pattern of results. The right hemisphere as depicted by console data did not show significant intergroup differences for handedness. Left hemispheres in the console data showed significant differences at the 90% and 80% points between Rh(c) and RhL(c), a relation not observed in the trace data (see Figure 10). A summary of the significant trace and console ANOVA's for Hand × Left and Right sides can be seen in Table 7.

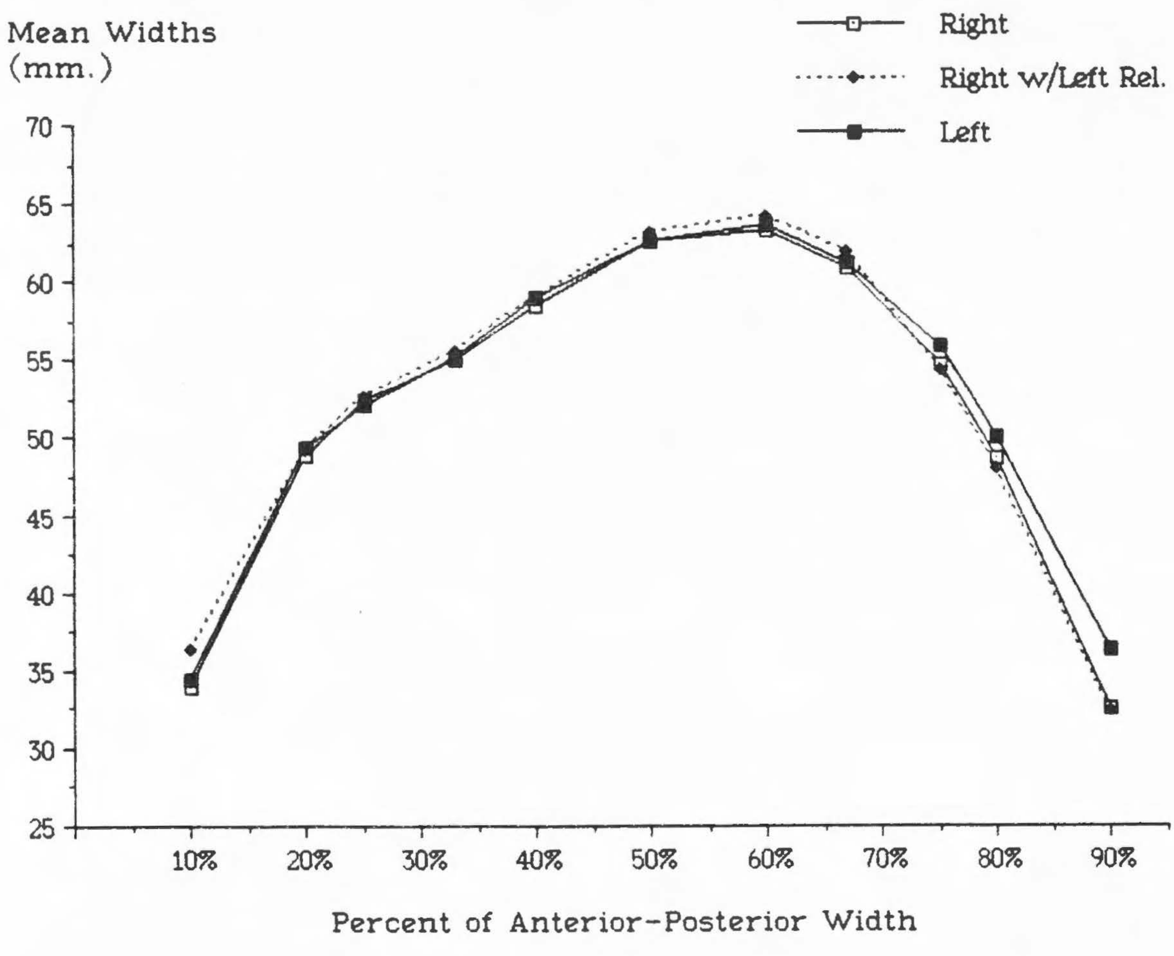


Figure 10. Console right-hemisphere widths by handedness group.

Table 7

Analysis of Variance F Values and Associated Significance of CT Trace and Console Data Right- and Left-Hemisphere Widths

			ANOVA	
Right hemisphere widths, trace data			*F*	Sig.(p=)
Handedness group	Mean	SD		Sig. pairs
Right Oc. 1 (90% of AP)			2.6924	.0724
Rh(t) (n=68)	26.970	5.223		
Rhl(t) (n=24)	28.583	4.995		none
Lh(t) (n=16)	29.937	3.838		
Right Oc. 2 (80% of AP)			3.5339	.0327
Rh(t)	46.044	4.005		
Rhl(t)	46.208	3.401	Sig. diff 1 & 3,	
Lh(t)	48.813	3.371		2 & 3
Right Oc. 3 (75% of AP)			4.6276	.0119
Rh(t)	51.897	4.125		
Rhl(t)	52.458	3.623	Sig. diff 1 & 3	
Lh(t)	55.250	3.751		2 & 3
Right Oc. 4 (67% of AP)			2.9854	.0548
Rh(t)	59.382	3.408		
Rhl(t)	59.750	3.220		none
Lh(t)	61.687	3.609		
Right TP 2 (60% of AP)			3.6543	.0292
Rh(t)	62.000	3.355		
Rhl(t)	62.708	3.303	Sig. diff. 1 & 3	
Lh(t)	64.562	3.915		
Console data				
Left Oc. 1 (90% of AP)			5.4705	.0063
Rh(c)	33.918	3.741		
Rhl(c)	37.428	2.409	Sig. diff 1 & 2	
Lh(c)	36.500	5.822		
Left Oc. 2 (80% of AP)			4.5436	.0142
Rh(c)	50.122	3.539		
Rhl(c)	53.214	3.118	Sig. diff 1 & 2	
Lh(c)	50.167	2.994		

Left÷Right Ratios and Left-Right
Differences by Hand

When ratios and difference scores were used to study the neuroanatomical asymmetries, the focus moved from the relation of handedness to the hemispheres in isolation to the relations between the hemispheres themselves as mediated by handedness. While the ANOVA's performed on the trace data did not reveal different information on the interaction of the hemispheres in terms of where significance was found, it was felt by the researcher that each method contributed different elements to the emerging picture. In the case of ratios, it was observed that console and trace measures on the same subjects were sometimes of different size. It was then decided to carry out an analysis on the ratio of left÷right sides, which would permit the study of the relation between the sides to be examined independent of the actual magnitude of the sides themselves. Conversely, since the tracings were still within the average size ranges for brains in the entire study, left-right difference scores were analyzed by handedness group to provide some clues as to the magnitude of the asymmetries between the hemispheres. Thus, the use of ratios and difference scores together was seen by the writer as a form of error control and for the way the two provide complementary information. Post-hoc comparisons were made with Fisher's least significant difference (LSD) test.

Beginning with trace data, L÷R ratios × Handedness group ANOVA's were significant at the $\alpha = .05$ level at the 80%, 75%, 67%, and 60% of AP points in the area designated as occipital and temporal/ parietal. In all four of these comparisons, Rh(t) was larger than

Lh(t). At the 75% and 67% of AP levels, Rhl(t) was also significantly different from Lh(t). No other ANOVA's performed on ratios at percentage points in the temporal/parietal or frontal areas were significant. In most of the comparisons that were significant, the Rh(t) and Rhl(t) ratios were greater than 1, indicating a larger left side, as compared with an Lh(t) ratio of less than one (e.g., .963), indicating a larger right side (See Figure 11).

Referring next to the console data, significant ANOVA's of L÷R ratios by handedness group were observed at 90% and 80% of AP, with 75% approaching but not reaching the significance level (p= .0529). Rhl(c) had the most left-leaning ratio, rendering it significantly different from groups Rh(c) and Lh(c), whose left÷right ratios were smaller in magnitude and closer to one (equality). Table 8 illustrates the significant ANOVA results and group differences for both console and trace data (See Figure 12).

ANOVAs performed on L-R differences × Handedness group provided additional and supporting information to the ratio data. Examining trace data first, significant F ratios were obtained at the 80%, 75%, 67%, and 60% AP points. In all four cases, Rh(t) differences were positive in sign (larger left than right) and Lh(t) differences were negative in sign (right side larger than left) and significant. In two of the ANOVA's (75% and 67% of AP) Rhl(t) mean difference scores were also significantly different from the Lh(t) subject scores. The magnitude of the significant differences between the three handedness-group brain measurements ranged from 2.313 to 3.97 millimeters.

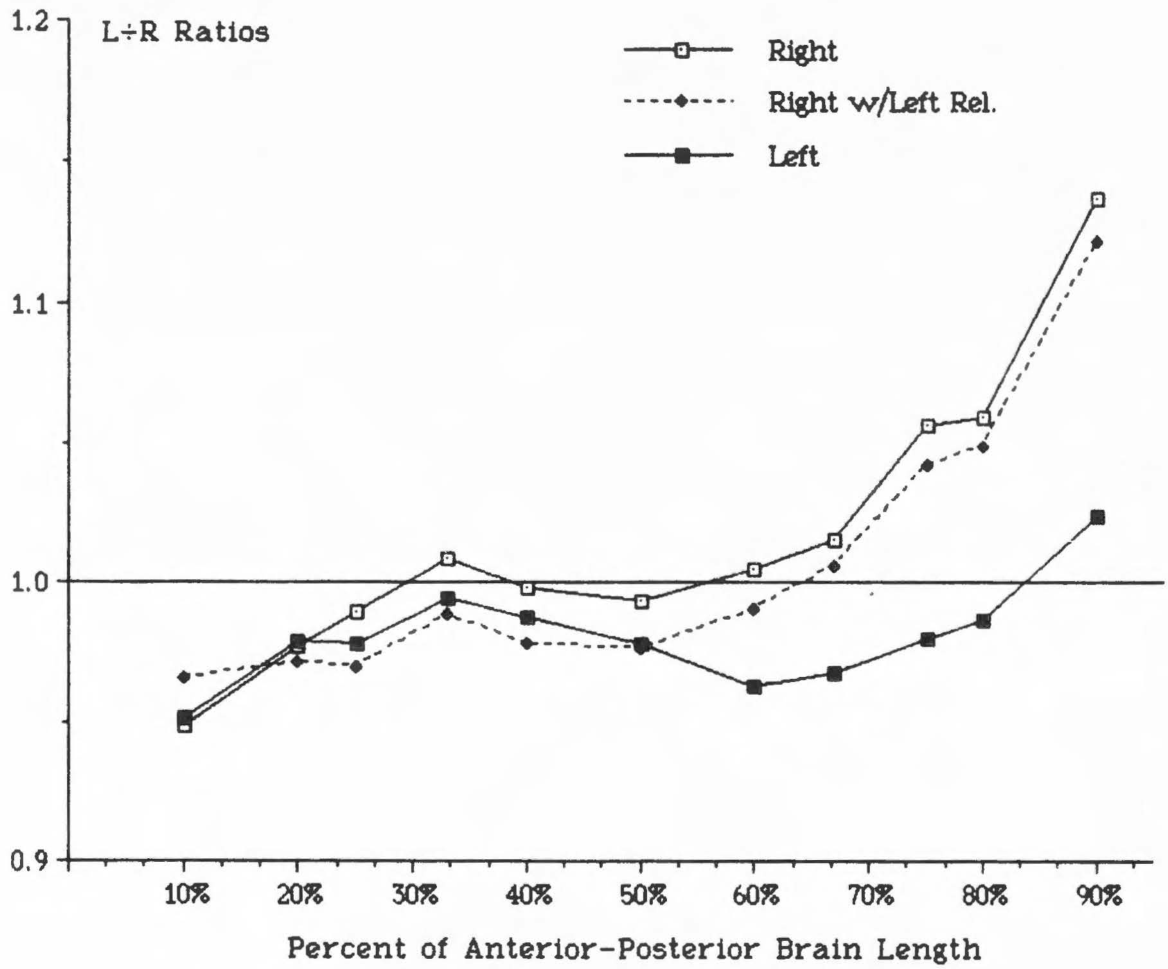


Figure 11. L÷R ratios by handedness group, trace data.

Table 8

Analysis of Variance F Values and Associated Significance of CT Trace and Console Data, L÷R Ratios

Trace data L÷R ratios Handedness group	Mean	SD	ANOVA *F*	Sig. (p=) Sig. pairs
L÷R Oc. 2 (80% of AP)			3.5934	.0309
Rh(t)	1.059	.099		
Rhl(t)	1.049	.096	Sig. diff	1 & 3
Lh(t)	.987	.087		
L÷R Oc. 3 (75% of AP)			5.2024	.0070
Rh(t)	1.057	.089		
Rhl(t)	1.042	.081	Sig. diff	1 & 3
Lh(t)	.980	.074		2 & 3
L÷R Oc. 4 (67% of AP)			4.3724	.0150
Rh(t)	1.016	.062		
Rhl(t)	1.006	.052	Sig. diff	1 & 3
Lh(t)	.988	.046		2 & 3
L÷R TP 2 (60% of AP)			4.578	.0124
Rh(t)	1.005	.056		
Rhl(t)	.991	.039	Sig. diff	1 & 3
Lh(t)	.963	.042		
Console data L÷R ratios				
L÷R Oc. Ratio 1 (90% of AP)			3.7070	.0298
Rh(c)	1.0548	.153		
Rhl(c)	1.1654	.111	Sig. diff	2 & 3,
Lh(c)	1.0109	.159		2 & 1
L÷R Oc. Ratio 2 (80% of AP)			6.5913	.0025
Rh(c)	1.0315	.078		
Rhl(c)	1.1090	.072	Sig. diff	2 & 3,
Lh(c)	1.0070	.059		2 & 1
L÷R Oc. Ratio 3 (75% of AP)			3.0740	.0529
Rh(c)	1.0181	.068		
Rhl(c)	1.0667	.059		none
Lh(c)	1.0140	.071		

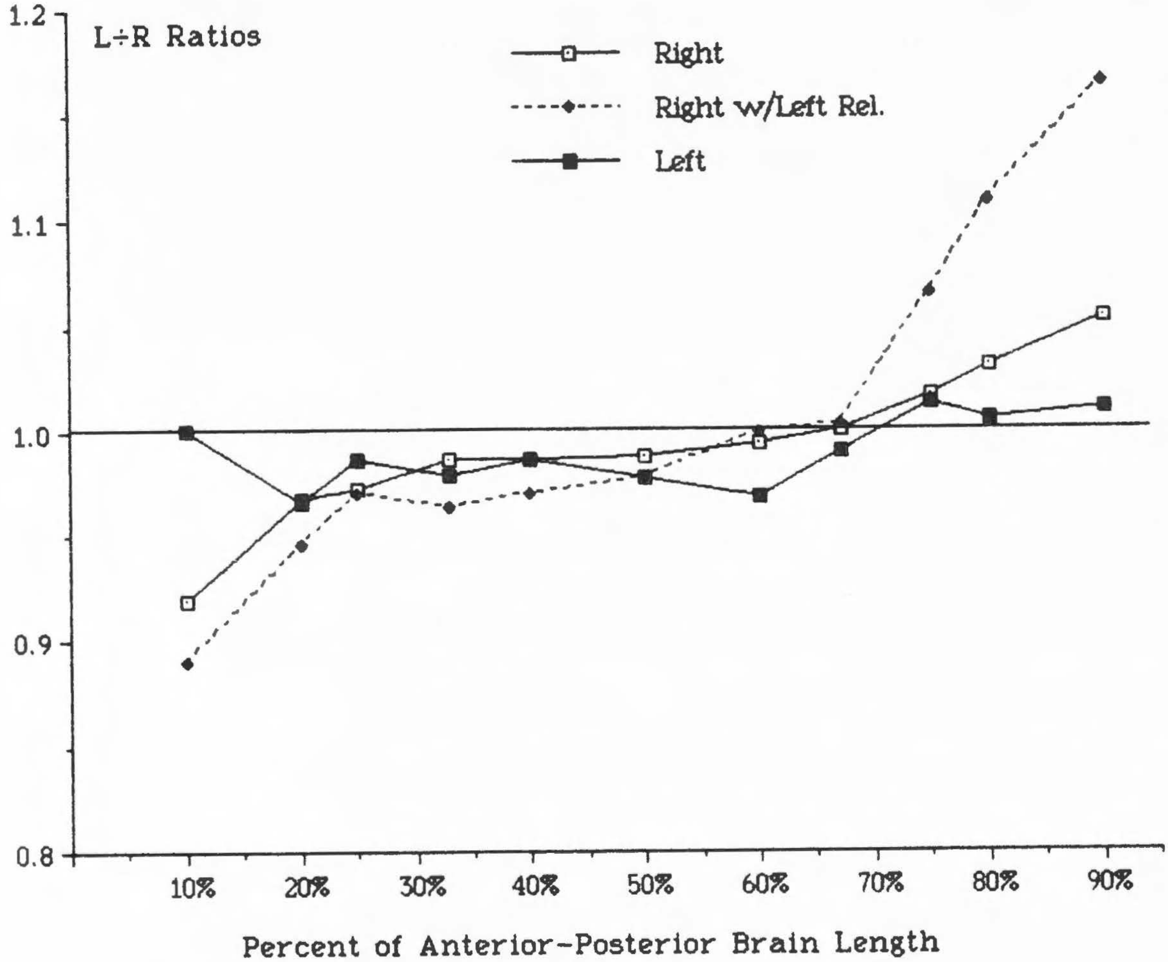


Figure 12. Console L÷R ratios by handedness group.

ANOVA's performed on L-R differences by handedness group provide a complementary picture to the ratio data. Examining trace data first, significant F ratios were obtained at the 80%, 75%, 67%, and 60% AP points. In all four cases, Rh(t) differences were positive in sign (left larger than right) and Lh(t) differences were negative in sign (right larger than left) and represented significant differences between these two groups. In two of the ANOVA's (OC3, 75% and OC4, 67% of AP) Rhl(t) mean difference scores were also significantly different from the Lh(t) scores. The magnitude of the significant differences between the three handedness group brain measurements ranged from 2.31 to 3.97 millimeters (See Figure 13).

ANOVA's performed on console data L-R differences by handedness group yielded significant F ratios at 90%, 80% and 75% of AP. In all three of the significant ANOVAs, Rhl(c) was of greater positive magnitude than Rh(c) (which was also greater than zero). Rhl(c) was significantly greater than Lh(c) in two of the three ANOVAs of interest, at 90% and 80% of AP, respectively. The Lh(c) left-right differences were also in the positive direction. The differences between significant pairs ranged in magnitude from 2.67 mm to 4.98 mm. Table 9 illustrates the significant ANOVA's for both trace and console difference-score data (See Figure 14).

To summarize the results of the ANOVA analysis of right- and left-hemisphere widths, L÷R ratios, and L-R difference measures, significant differences were observed in the posterior half of the right hemisphere (in the trace data). Lh(t) had significantly wider right-hemisphere measures than Rh(t) in three out of three significant

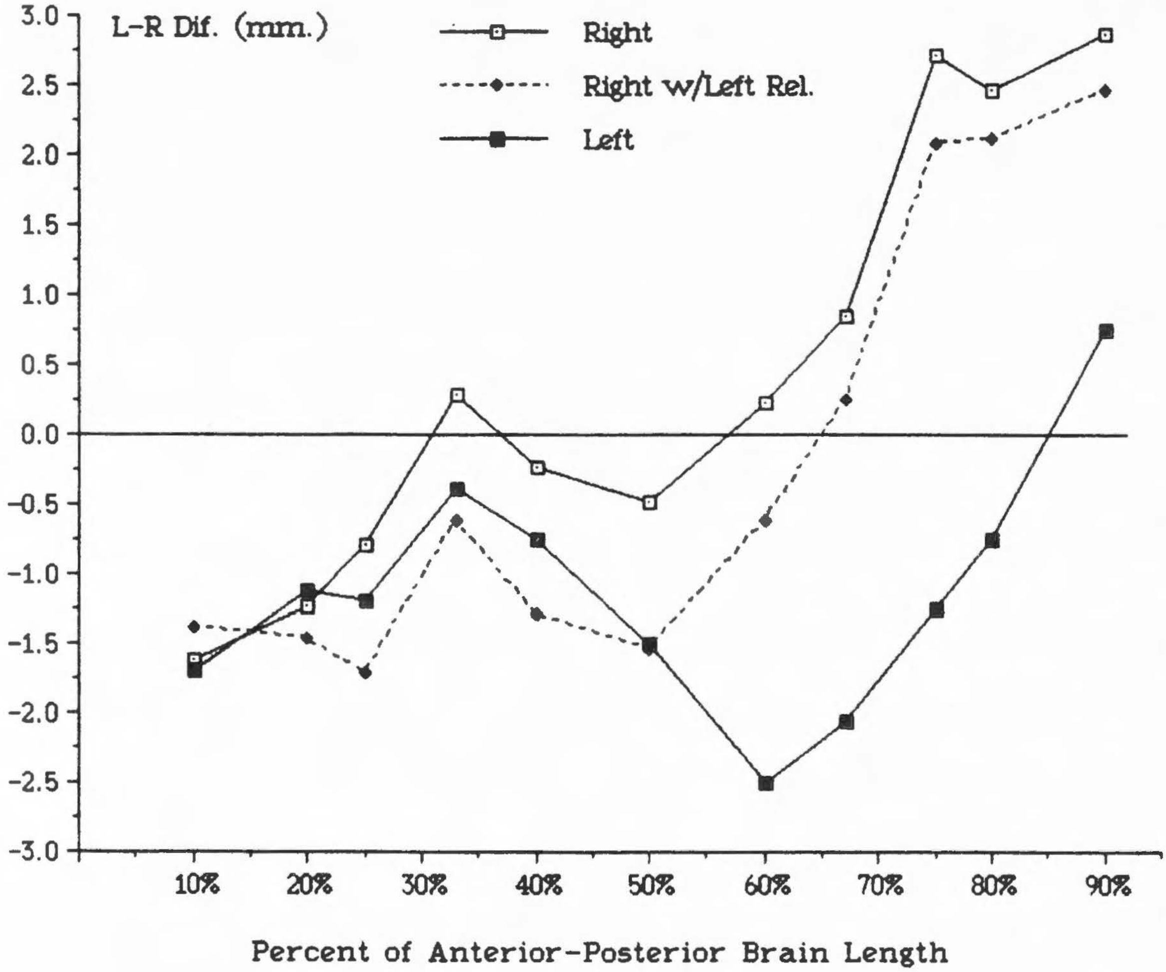


Figure 13. L-R differences by handedness group, trace data.

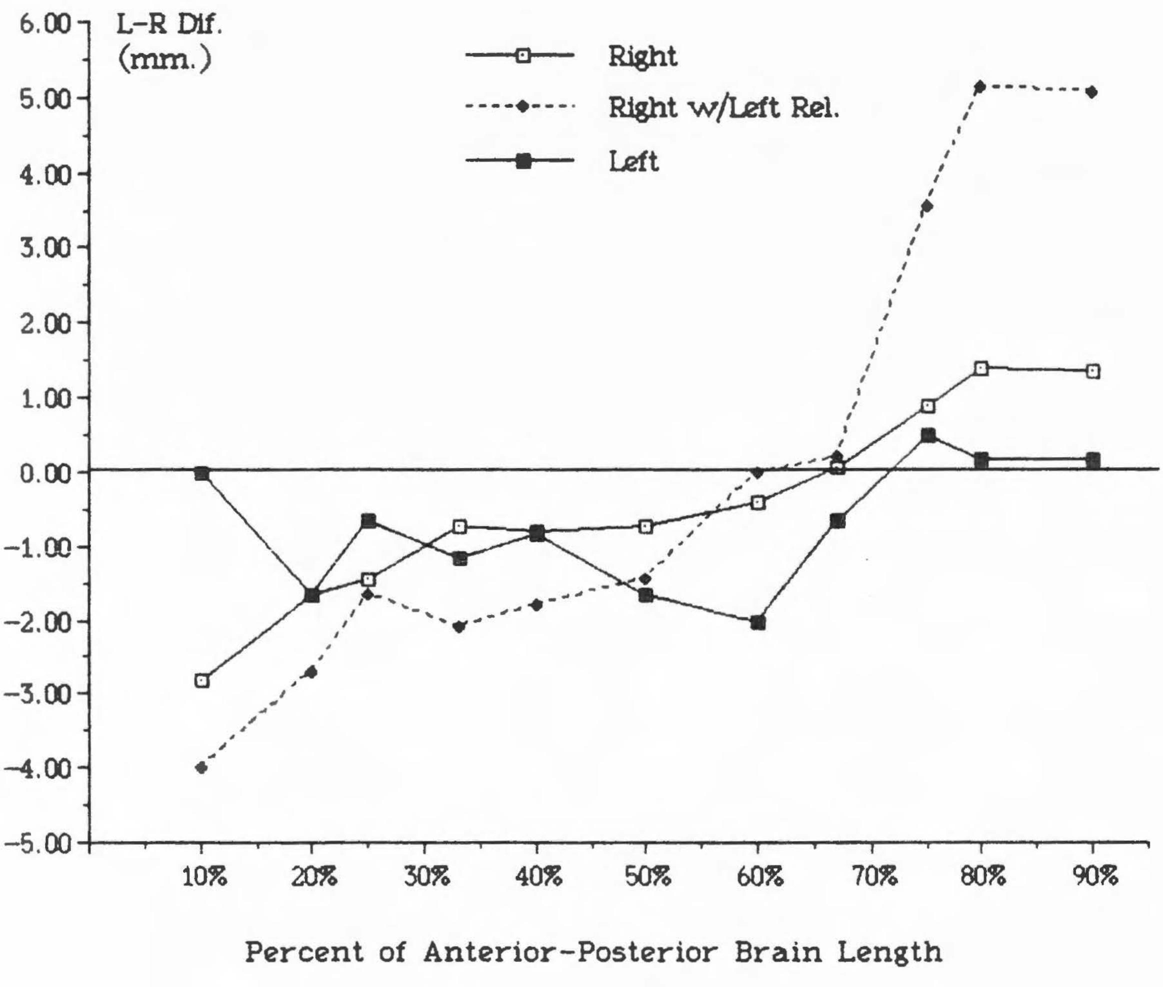


Figure 14. Console L-R differences by handedness group.

Table 9

Analysis of Variance F Values and Associated Significance of CT Trace and Console Data Left-Right Difference Measures

			ANOVA	
Trace data L-R difference scores			F	Sig. (p=)
L-R Oc. 2 (80% of AP)			3.3560	.0387
Rh(t)	2.471	4.615		
Rhl(t)	2.125	4.317	Sig. diff 1 & 3	
Lh(t)	-0.750	4.219		
L-R Oc. 3 (75% of AP)			5.3982	.0059
Rh(t)	2.721	4.488		
Rhl(t)	2.083	4.096	Sig. diff 1 & 3	
Lh(t)	-1.250	4.107	2 & 3	
L-R Oc. 4 (67% of AP)			4.5039	.0133
Rh(t)	.838	3.704		
Rhl(t)	.250	3.082	Sig. diff 1 & 3	
Lh(t)	-2.063	2.977	2 & 3	
L-R T-P 2 (60% of AP)			4.7542	.0106
Rh(t)	.235	3.503		
Rhl(t)	-0.625	2.516	Sig. diff 1 & 3	
Lh(t)	-2.500	2.898		

Console data L-R difference scores				
L-R Dif. Oc. 1 (90% of AP)			4.0645	.0216
Rh(c)	1.3673	4.773		
Rhl(c)	5.0714	3.293	Sig. diff 2 & 3,	
Lh(c)	.1667	5.672	2 & 1	
L-R Dif. Oc. 2 (80% of AP)			6.6547	.0023
Rh(c)	1.3878	3.388		
Rhl(c)	5.1429	3.325	Sig. diff 2 & 3,	
Lh(c)	.1667	3.061	2 & 1	
L-R Dif. Oc. 3 (75% of AP)			3.3845	.0399
Rh(c)	.8980	3.601		
Rhl(c)	3.5714	3.031	Sig. diff 2 & 1	
Lh(c)	.5000	3.728		

comparisons, and Rhl(t) was significantly smaller than Lh(t) in two of the three comparisons. Rh(t) and Rhl(t) were not significantly different from each other. Both ratio and difference measures indicated significant between-group differences in the posterior half of the CT slice studied. Rh(t) ratios and difference scores ranged from levels signifying a left hemisphere larger than the right to relative equality between the hemispheres. Lh(t) ratios in the significant comparisons ran in the opposite direction, with right sides larger than the left. The anterior half of the slice did not show the same interaction between left and right measures.

Console data pointed in different directions from trace data. Intergroup variability in the hemispheres was more prominent on the left side in the console and on the right in the trace data. In addition, the variability that was noted was in a different location in the first two of the five left-posterior measures (OC1, 90%, and OC2, 80% of AP). The leading group in this case was Rhl(c), presenting with a larger left width than that of Rh(c). Two ANOVA's by L÷R (OC1, 90%, and OC2, 80% of AP) ratio were significant, with Rhl(c) exceeding both Rh(c) and Lh(c) in left-side magnitude in relation to right. All three handedness groups were represented with ratios greater than one at both the 90% and 80% levels, indicating a range from near equality of the hemispheres to a larger left side. Difference Scores × Handedness group ANOVA outcomes in the console set were consistent with the other results, with significant F ratios at 90%, 80%, and 75% of AP.

Relations Between Measurements in the Same Brain

Pearson product moment correlation coefficients were computed between all 11 L÷R ratios in the trace and console data. This was done in order to study the extent to which these measures were related to each other. For the trace data set (N=108) correlations between adjacent pairs of measures in the posterior half of the CT slice were: OC1 (90%)/OC2 (80%)= .69 (p= .000), OC2/OC3 (75%)= .82 (p= .000), OC3/OC4 (67%)= .79 (p= .000), and OC4/TP2 (60%)= .82 (p= .000). The same four pairs in Rhl(t) were also highly correlated, as follows: OC1(90%)/OC2= .77 (p= .000), OC2/OC3= .77 (p= .000), OC3/OC4= .72 (p= .000), and OC4/TP2= .84 (p= .000). Both Rhl(t) (n= 24) and Lh(t) (n= 16) show a reduction in the OC1 and OC2 correlation, with Rhl(t) showing .51 (p= .005) and Lh(t) showing .62 (p= .004) for that pair. The other pairs in Rhl(t) were also quite high, with OC2/OC3= .88 (p= .000), OC3/OC4= .86 (p= .000), and OC4/TP2= .71 (p= .000). The Lh(t) correlation coefficient values for these pairs of ratios were OC2/OC3= .89 (p= .000), OC3/OC4= .87 (p= .000), and OC4/TP2= .685 (p= .001). All these correlations are significant beyond the α= .01 level despite the impact of sample size on the probability of chance results of the same magnitude. Tables 10 through 17 depict correlations for the console and trace data sets and the handedness groups.

Examining the other pairs of correlations derived from the L÷R ratios of trace data revealed that all of the measurements on the diagonal were significantly correlated in the trace set and in handedness Rh(t). The relations between adjacent measures in the upper temporal/parietal (TP4, 40%) and frontal (Fr1-4, 33, 25, 20, and

Table 10

<u>Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Traced Subjects (n=108)</u>

	OC1	OC2	OC3	OC4	TP2	TP3	TP4	FR1	FR2	FR3	FR4
OC1			.66	.52				-.14	-.13	-.28	-.265
P=			.000	.000				.069	.091	.001	.003
OC2	.69			.76						-.17	
P=	.000			.000						.036	
OC3		.82			.58				-.26		
P=		.000			.000				.003		
OC4			.79					-.11			
P=			.000					.133			
TP2				.82							
P=				.000							
TP3					.64						
P=					.000						
TP4						.45					
P=						.000					
FR1							.69				
P=							.000				
FR2								.62			
P=								.000			
FR3									.50		
P=									.000		
FR4										.31	
P=										.000	

Table 11

Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Traced Right-Handed Subjects. (n=68)

	OC1	OC2	OC3	OC4	TP2	TP3	TP4	FR1	FR2	FR3	FR4
OC1			.64	.48				-.11	-.10	-.40	-.34
P=			.000	.000				.191	.215	.000	.003
OC2	.77			.72						-.35	
P=	.000			.000						.002	
OC3		.77			.51				-.32		
P=		.000			.000				.003		
OC4			.72					-.20			
P=			.000					.052			
TP2				.84			-.13				
P=				.000			.142				
TP3					.625						
P=					.000						
TP4						.405					
P=						.000					
FR1							.75				
P=							.000				
FR2								.71			
P=								.000			
FR3									.50		
P=									.000		
FR4										.33	
P=										.003	

Table 12

Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Traced Righthanders w/ Left Relatives (n=24)

	OC1	OC2	OC3	OC4	TP2	TP3	TP4	FR1	FR2	FR3	FR4
OC1			.72	.61				-.41	-.39	-.30	-.32
P=			.000	.001				.022	.031	.080	.063
OC2	.51			.77						.17	
P=	.005			.000						.202	
OC3		.88			.56				-.21		
P=		.000			.001				.165		
OC4			.86					-.02			
P=			.000					.467			
TP2				.71			.21				
P=				.000			.189				
TP3					.65						
P=					.000						
TP4						.54					
P=						.003					
FR1							.38				
P=							.035				
FR2								.18			
P=								.205			
FR3									.52		
P=									.004		
FR4										.65	
P=										.000	

Table 13

Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Traced Left-Handed Subjects.(n=16)

	OC1	OC2	OC3	OC4	TP2	TP3	TP4	FR1	FR2	FR3	FR4
OC1			.63	.47				.14	.005	.18	-.10
P=			.003	.028				.292	.493	.247	.345
OC2	.62			.79						.32	
P=	.004			.000						.105	
OC3		.89			.705				-.18		
P=		.000			.001				.246		
OC4			.87					.21			
P=			.000					.209			
TP2				.685			.36				
P=				.001			.077				
TP3					.73						
P=					.001						
TP4						.66					
P=						.003					
FR1							.73				
P=							.001				
FR2								.39			
P=								.067			
FR3									.46		
P=									.035		
FR4										.07	
P=										.400	

Table 14

Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Console Subset (n=69)

	OC1	OC2	OC3	OC4	TP2	TP3	TP4	FR1	FR2	FR3	FR4
OC1			.55	.57				-.05	-.16	-.28	-.33
P=			.000	.000				.329	.086	.009	.003
OC2	.69			.50						-.22	
P=	.000			.000						.037	
OC3		.78			.46				-.15		
P=		.000			.000				.114		
OC4			.49					.10			
P=			.000					.208			
TP2				.32			.01				
P=				.004			.465				
TP3					.39						
P=					.000						
TP4						.20					
P=						.053					
FR1							.39				
P=							.000				
FR2								.31			
P=								.005			
FR3									.34		
P=									.002		
FR4										.31	
P=										.005	

Table 15

Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Console Subset, Right-Handed Subjects (n=49)

	OC1	OC2	OC3	OC4	TP2	TP3	TP4	FR1	FR2	FR3	FR4
OC1			.53	.65				.07	−.12	.32	−.38
P=			.000	.000				.325	.210	.011	.004
OC2	.74			.59						−.26	
P=	.000			.000						.037	
OC3		.74			.44				−.12		
P=		.000			.001				.195		
OC4			.57					.16			
P=			.000					.137			
TP2				.33							
P=				.011							
TP3					.43						
P=					.001						
TP4						.19					
P=						.098					
FR1							.38				
P=							.004				
FR2								.29			
P=								.011			
FR3									.32		
P=									.011		
FR4										.33	
P=										.011	

Table 16

Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Console Subset, Right-Handers with Left-Handed Relatives (n=14)

	OC1	OC2	OC3	OC4	TP2	TP3	TP4	FR1	FR2	FR3	FR4
OC1			.28					-.28	-.47	-.36	.26
P=			.167					.161	.045	.105	.188
OC2	.20			.11						.06	
P=	.241			.348						.419	
OC3		.78			.70				-.07		
P=		.000			.002				.402		
OC4			.008					-.10			
P=			.490					.363			
TP2				.04							
P=				.452							
TP3					.45						
P=					.053						
TP4						.26					
P=						.184					
FR1							.45				
P=							.054				
FR2								.66			
P=								.005			
FR3									.50		
P=									.035		
FR4										.28	
P=										.169	

Table 17

Pearson Correlation Coefficients Between Adjacent and Distant Ratios in Console Subset, Left-Handed Subjects (n=6)

	OC1	OC2	OC3	OC4	TP2	TP3	TP4	FR1	FR2	FR3	FR4
OC1			.65					.06	.07	.71	-.77
P=			.081					.455	.449	.057	.038
OC2	.58			.69						.49	
P=	.112			.062						.162	
OC3		.91			.38				-.50		
P=		.006			.226				.156		
OC4			.65					-.10			
P=			.080					.425			
TP2				.78							
P=				.034							
TP3					-.79						
P=					.031						
TP4						-.51					
P=						.149					
FR1							-.14				
P=							.393				
FR2								-.66			
P=								.079			
FR3									.16		
P=									.379		
FR4										-.36	
P=										.243	

10%) appeared to be more variable than those of the posterior portion of the slice studied. This was especially true in Rhl(t) and Lh(t), where Fr1/Fr2 were correlated with an r of .18 in Rhl(t) and .39 in Lh(t). Neither of these correlations were significant at an α of .05. Correlations for the trace set and Rh(t) on the Fr1/Fr2 pairs were .62 and .71, respectively, and significant beyond an α of .01. Fr2/Fr3 were positively correlated in all three groups and the trace set as follows: For the trace set and Rh(t) Fr2/Fr3= .50 (p= .000), Rhl(t)= .52 (p= .004), and Lh(t)= .46 (p= .035). Finally, the correlation between the last pair, Fr3/Fr4, ranged from .31 and .33 (p= .000 and .003) in the trace set and Rh(t) to .65 in Rhl(t) and .07 in Lh(t) (p= .000 and .400).

Across groups in the trace data, the pairs of adjacent ratios in the posterior half of the brain slice studied were fairly strongly and consistently correlated—especially the OC2/OC3, OC3/OC4, and OC4/TP2 pairs. While many other significant correlations were notable, the between measure level correlations were more variable between the anterior measures of the brain. This was most true in Rhl(t) and Lh(t), even allowing for the impact of sample size on the significance of given correlations.

In the console data set, the problem of sample size and statistical significance was, of course, compounded. However, the results differed in other respects as well. For the entire console data set (n= 69), correlations between adjacent pairs in the posterior half of the slice were greater than zero. The correlations for the pairs were as follows: OC1/OC2= .69 (p= .000), OC2/OC3= .78 (p= .000), OC3/OC4= .49

(p= .000), and OC4/TP2= .32 (p= .004). The same four pairs in Rh(c) (n= 49) were: OC1/OC2= .74 (p= .000), OC2/OC3= .74 (p= .000), OC3/OC4= .57 (p= .000), and OC4/TP2= .33 (p= .011). Rhl(c) and Lh(c) both showed the impact of smaller sample size and possible other factors in the four occipital temporal/parietal pairs. For Rhl(c) (n= 14), the correlations were: OC1/OC2= .20 (p= .241), OC2/OC3= .78 (p= .000), OC3/OC4= .008 (p= .490), and OC4/TP2= .04 (p= .452). Even allowing for a small *n*, these results differ considerably from those of the Rhl trace data results. The console subset of Lh(c), with six subjects, was arguably too small for meaningful analysis at this level. However, for comparison's sake, the *r*'s from the four pairs of measurements from the group three console data are: OC1/OC2= .58 (p= .112), OC2/OC3= .91 (p= .006), OC3/OC4= .65 (p= .080), and OC4/TP2= .78 (p= .034).

Turning attention to the upper-temporal parietal and frontal ratios, the console subset and Rh(c) ratios were greater than zero and significant, as shown here: TP4/Fr1= .39 (p= .000) Fr1/Fr2= .31 (p= .005), Fr2/Fr3= .34 (p= .002), and Fr3/Fr4= .31 (p= .005). Rh(c) frontal pairs were also greater than zero and significant, as follows: TP4/Fr1= .38 (p= .004) Fr1/Fr2= .29 (p= .011), Fr2/Fr3 = .32 (p= .011), and Fr3/Fr4= .33 (p= .011). While these correlations were positive and significant for the console set and Rh(c) console data, they illustrated weaker overall relations between adjacent measures. In Rhl(c), two of the four correlations were significant and the rest were nonsignificant despite being of comparable magnitude to those cited above: TP4/Fr1= .45 (p= .054) Fr1/Fr2= .66 (p= .005), Fr2/Fr3= .50 (p= .035), and Fr3/Fr4= .28 (p= .169). In Lh(c), none of the anterior correlations were significant, and all were less than zero with the exception of the Fr2/Fr3 pair (r = .16). The only significant correlation on the diagonal outside of the four occipital and occipital temporal/parietal pairs already reported was at TP2/TP3 (50%)= -.79 (p= .034), of equal magnitude but opposite sign to the previous pair, OC4/TP2.

It seems reasonable to suggest at this point that there are important differences between intermeasurement relations by measurement method (trace and console). To a lesser extent, the handedness groups in the trace data set appear to have differences in intermeasurement correlation that are most marked when the posterior and anterior correlations are compared. The posterior correlations are generally higher than the anterior correlations and nearer to each other in magnitude, while the anterior correlations are generally smaller in magnitude and more variable [most notably in Rhl(t) and Lh(t)].

Last to be mentioned in this section on intermeasurement correlations is a small inverse relation between the posterior and anterior measurements. As diagrammed in the upper right-hand corner of Tables 9 through 16, OC1/Fr4, OC2/Fr3, and OC3/Fr2 in the entire trace set and Rh(t) show this inverse relation. The magnitudes of the correlations range from -.265 to -.17 in the entire trace set and -.35 to -.32 in Rh(t). This relation is not present in Rhl(t) and Lh(t) to the same degree and is not significant. The console data are also inconsistent in this area.

Differences in Frequencies of Asymmetry by Handedness

Chi-square tests were performed on both data sets in order to determine if neuroanatomical asymmetries as expressed in L-R differences were differentially distributed by handedness category. Much of the research in the area of neuroanatomical asymmetry is carried out in terms of categorical definitions of asymmetry (see LeMay, 1977) and employed chi-square as the major method of analysis. In this study, the use of chi-square was partly to see to what extent the findings of other studies might be replicated. Asymmetries were defined as any L-R difference greater or less than ±1.00 millimeter. Less stringent criteria did not necessarily result in more significant findings but did yield a different pattern of results.

Chi-squares conducted on the trace data showed similar percentages when compared to other studies in this area. Significant χ^2 coefficients were obtained at the 75%, 67%, and 60% points of AP. The percentages of asymmetries at the 75% AP point appear in Table 18.

Table 18

Chi-Square Frequencies of Asymmetry in the Handedness Groups, 75% of AP (Trace)

Measurement point: 75% # of cases per cell **Column %**	Handedness Groups Rh	 Rhl	 Lh
Left side greater	42 **61.8**	13 **54.2**	4 **25.0**
Right side greater	8 **11.8**	5 **20.8**	8 **50.0**
Both sides equal	18 **26.5**	6 **25.0**	4 **25.0**

χ^2 Value = 12.99580 df = 4 p = .01130

Figures 15, 17, and 19 illustrate graphically the distributions of left and right asymmetries for each AP point in the three handedness groups for trace data. Figures 16, 18, and 20 illustrate the distributions of brains with left and right hemispheres of equal width.

Rh(t) is distributed in a similar fashion to the above at AP points 90% and 80%. What is probably of equal interest in the above table is the trend of the left-handed group in the opposite direction. Measurement point 67% appears to display a continuation of this trend, with Rh(t) chiefly represented in the first and third categories and Lh(t) represented in the second and third categories in Table 19.

Table 19

Chi-Square Frequencies of Asymmetry in the Handedness Groups, 67% of AP (Trace)

Measurement point: 67% # of cases per cell **Column %**	Handedness Groups Rh	 Rhl	 Lh
Left side greater	31 **45.6**	10 **41.7**	2 **12.5**
Right side greater	13 **19.1**	8 **33.3**	10 **62.5**
Both sides equal	24 **35.3**	6 **25.0**	4 **25.0**
χ^2 Value = 13.15895	df = 4		p = .01052

The Rh(t) and Rhl(t) subjects did not show marked or systematic departures from random representation in the asymmetry categories for a number of the measurement points from the temporal parietal to the frontal area. The next significant chi-square array, at 60% of AP is reproduced in Table 20. Noting the percentage of Lh(t) subjects in the right-size-larger category at this level and at level 67% and simultaneously noting the mean L-R difference scores reported at 67%

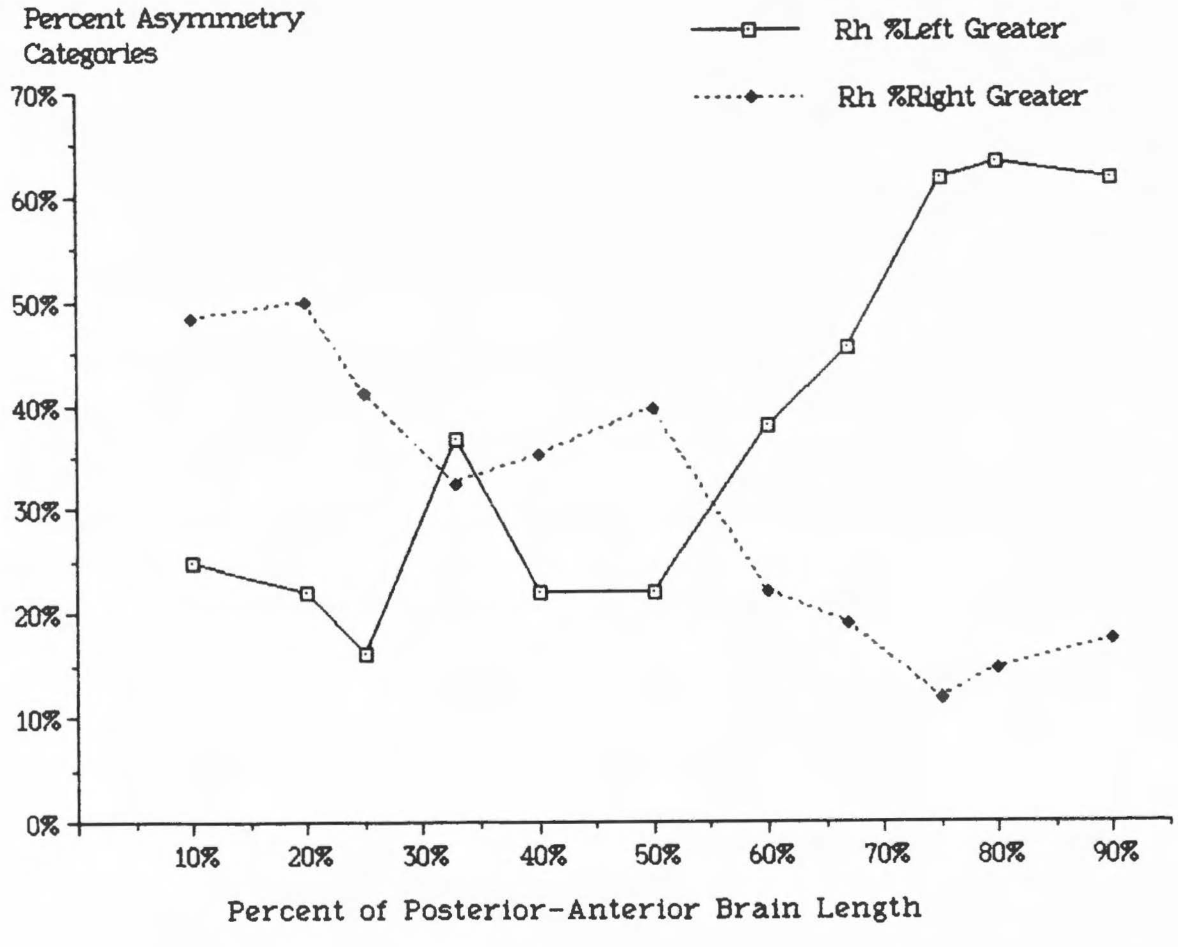


Figure 15. Percentages of asymmetries for right-handed subjects, trace data.

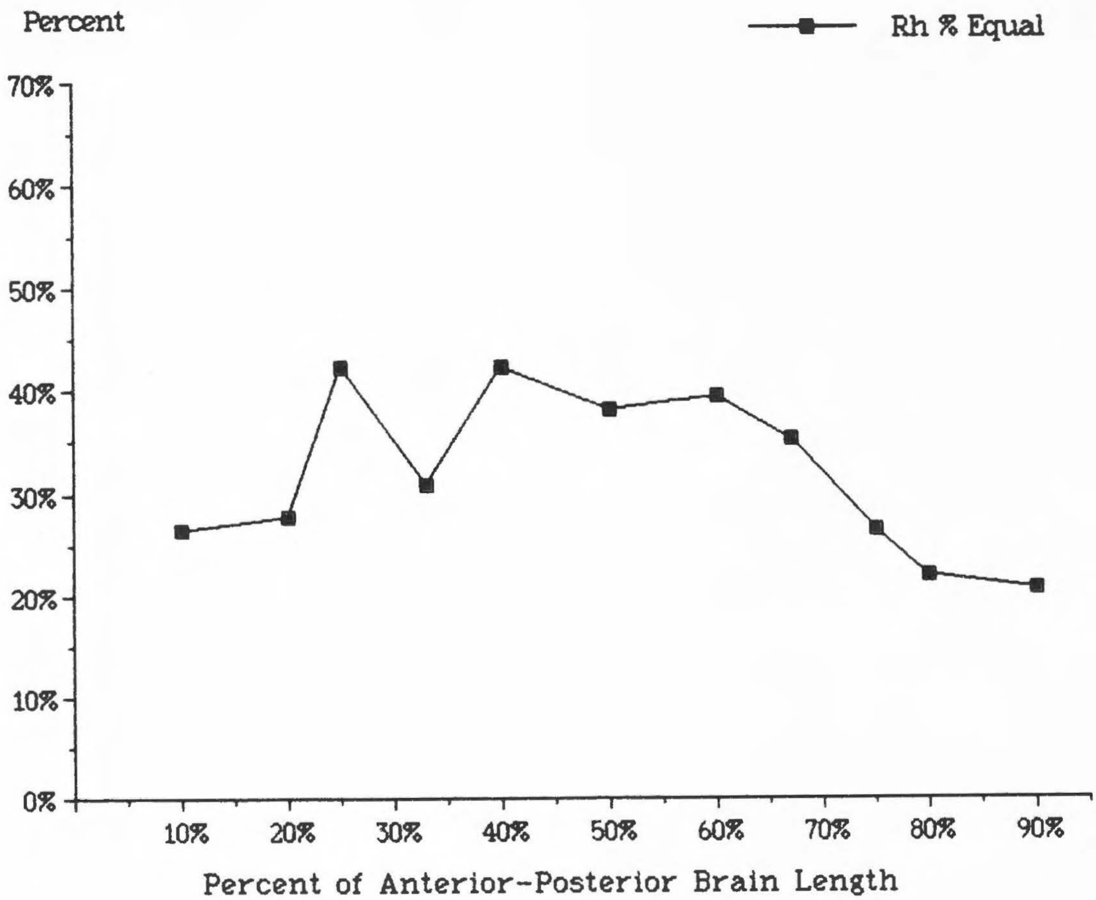


Figure 16. Percentages of symmetrical difference measures for right-handed subjects, trace data.

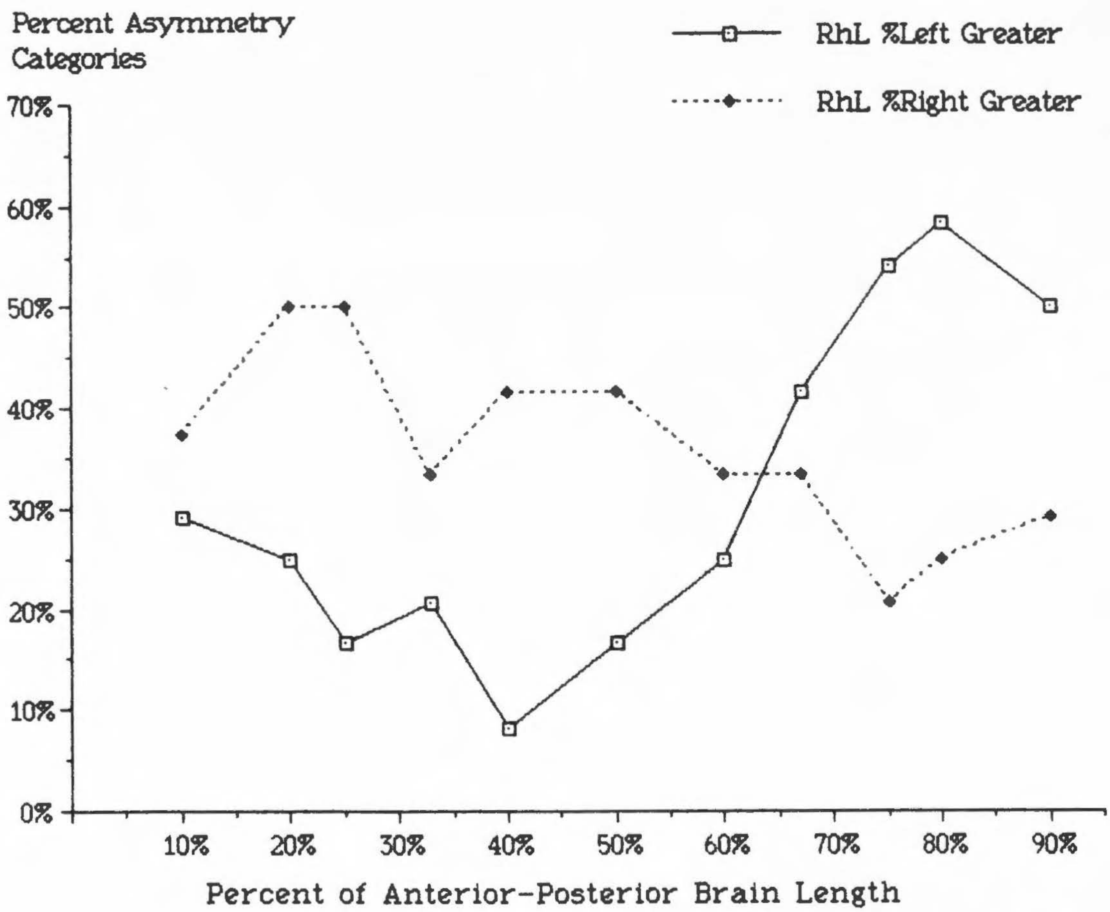


Figure 17. Percentages of left and right asymmetries for right-handed with left-handed relatives, trace data.

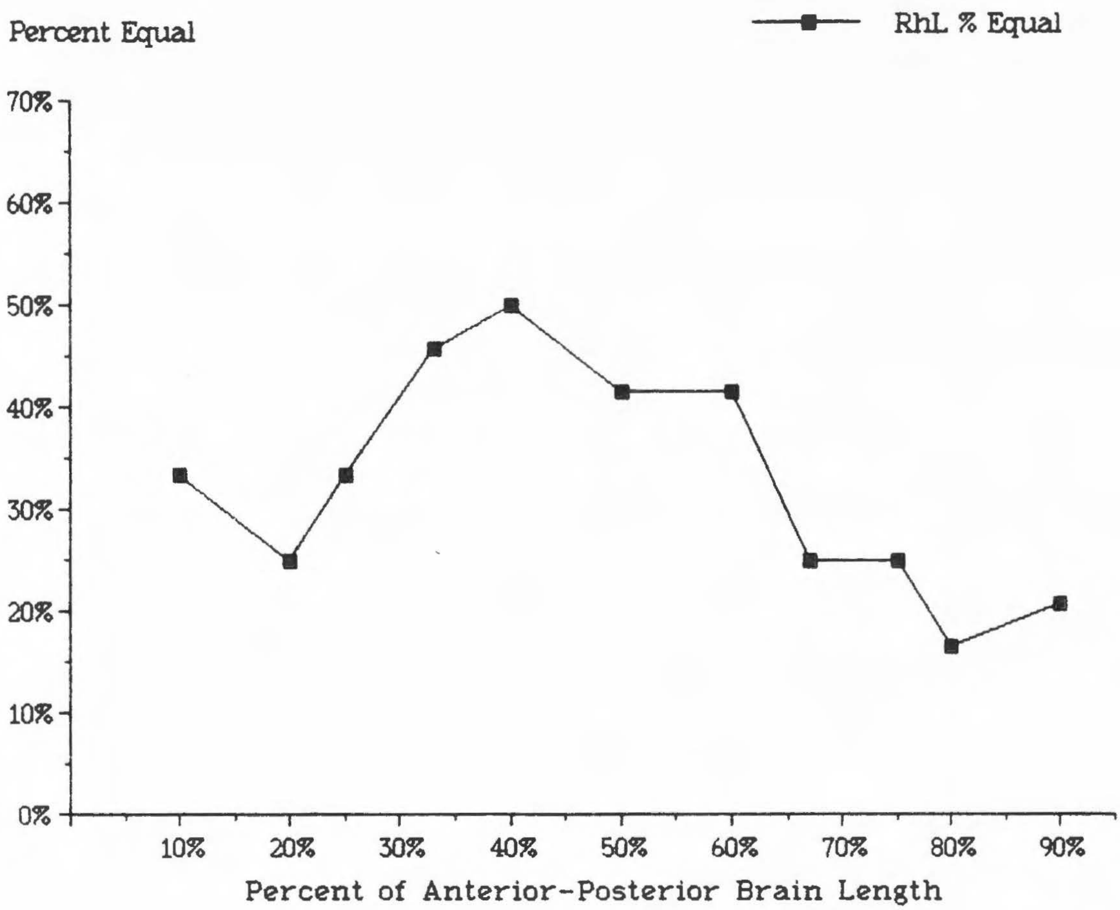


Figure 18. Percentages of symmetrical difference measures for right-handed with left-handed relatives, trace data.

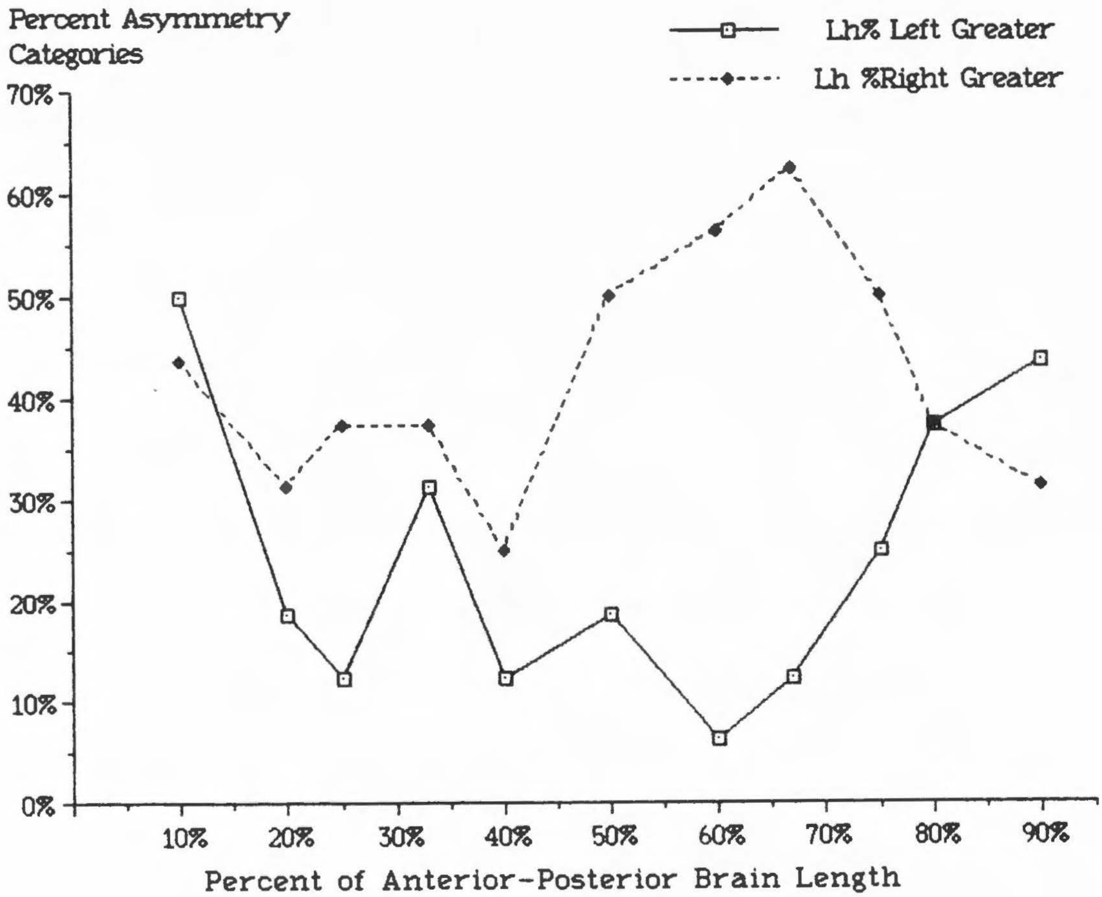


Figure 19. Percentages of left and right asymmetries for left-handed subjects, trace data.

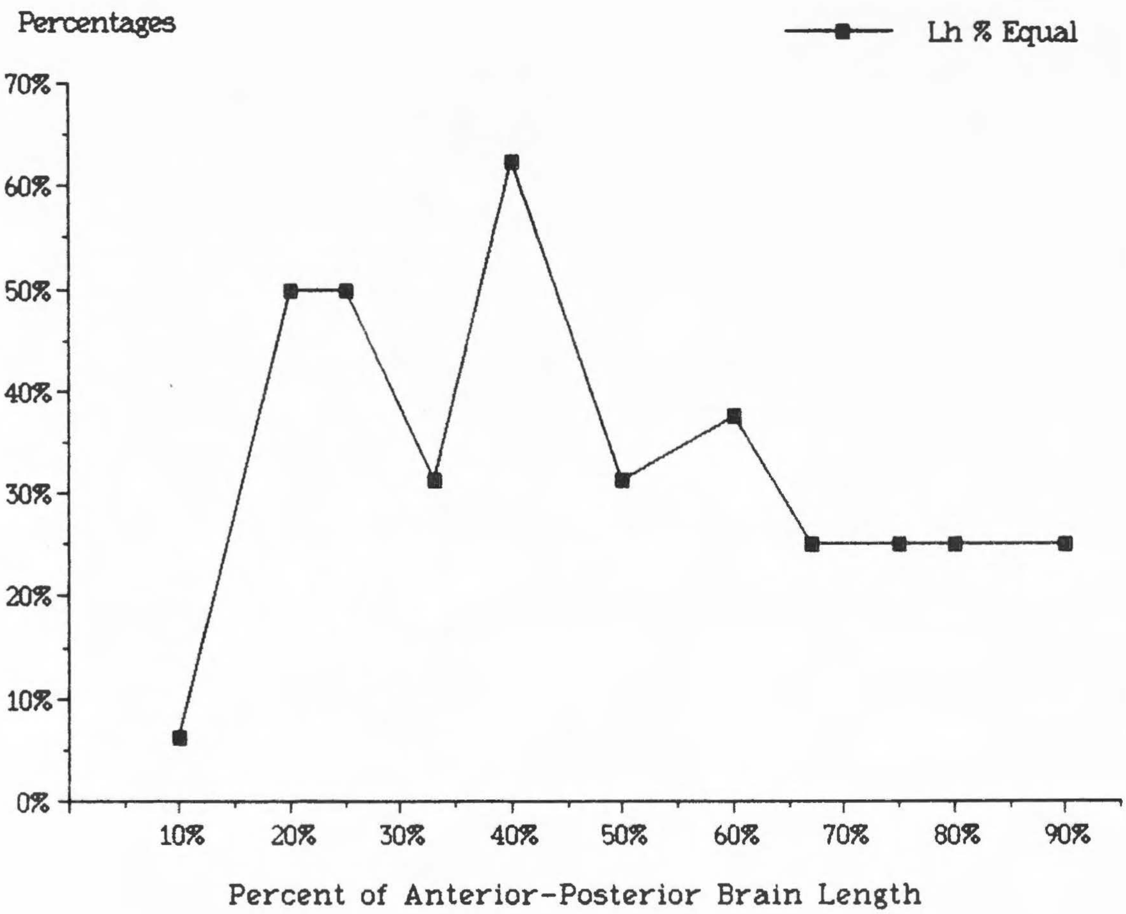


Figure 20. Percentages of symmetrical difference measures for left-handed subjects, trace data.

Table 20

Chi-Square Frequencies of Asymmetry in the Handedness Groups, 60% of AP (Trace)

Measurement point: 60% * of cases per cell **Column %**	Rh	Handedness groups Rhl	Lh
Left side greater	26 **38.2**	6 **25.0**	1 **6.3**
Right side greater	15 **22.1**	8 **33.3**	9 **56.3**
Both sides equal	27 **39.7**	10 **41.7**	6 **37.5**
χ^2 Value = 9.94402	df = 4		p = .04138

and 60% AP points in Table 9, one could speculate that it is the right-hemisphere measurements of Lh(t) that are defining the asymmetries at these levels of measurement. In other words, what is occurring at these percentages of brain length appears to be a right-hemisphere asymmetry in the left-handed group. In subsequent chi-square Tables, a movement of the percentages is visible in Rh(t) and Rhl(t), culminating in the pattern observed at AP point 20% (Table 21).

Table 21

Chi-Square Frequencies of Asymmetry by Handedness Groups, 20% of AP (Trace)

Measurement point: 20% * of cases per cell **Column %**	Rh	Handedness Groups Rhl	Lh
Left side greater	15 **22.1**	6 **25.0**	3 **18.8**
Right side greater	34 **50.0**	12 **50.0**	5 **31.3**
Both sides equal	19 **27.9**	6 **25.0**	8 **50.0**
χ^2 Value = 3.55999	df = 4		p = .46882

Due to the fact that the Rhl subjects (in trace data) frequently appeared to fall between the Rh(t) and Lh(t) subjects in terms of being less different from the former and insignificantly different from the latter, it was decided to rerun the chi-square analysis using only the Rh(t) and Lh(t) subjects. Because of the intermediate position of the Rhl(t) percentages, it was thought that the Rhl(t) percentages of asymmetries could possibly be obscuring significant differences between Rh(t) and Lh(t). The new analysis, using only the right- and left-handed subjects, did not result in any new findings of significantly different frequencies. The p values already observed were enhanced (the comparisons at 75%, 67%, and 60% all having p values beyond .01), and the comparisons at 80% and 10% of the AP measure moved closer to (but did not surpass) the α level of .05.

The constraints imposed on the usefulness of chi-square and other nonparametric tests is a matter of record (Loftus & Loftus, 1982). Although the percentages found at the occipital measurement points are comparable to those found in other studies (most notably LeMay, 1977 and LeMay & Kido, 1978), the smaller n in the present study limits the ability of the procedure to discriminate between the distributions of asymmetries across the handedness groups. Therefore, caution is advised drawing conclusions about the observed distributions of asymmetries.

In the console data, only one χ^2 coefficient exceeded the .05 level. This occurred at the 10% of AP point, the outermost measure of the frontal area (See Table 22). In view of the lack of agreement between console and trace data sets and the special problems with the small *n* of Lh in the console set, this discussion will be somewhat more limited than the foregoing. Consistent with the earlier leading role of the Rhl(c) ratios and difference scores in defining the ANOVA results in the 90%, 80%, and 75% occipital ratios, the Rhl(c) chi-square arrays reveal that 85.7% (12) of the 14 Rhl(c) subjects fall in the left side

Table 22

Chi-Square Frequencies of Asymmetry in the Handedness Groups, 10% of AP. (Console)

Measurement point: 10% \# of cases per cell **Column %**	Handedness Groups Rh	 Rhl	 Lh
Left side greater	8 **16.3**	1 **7.1**	1 **16.7**
Right side greater	38 **77.6**	12 **85.7**	2 **33.3**
Both sides equal	3 **6.1**	1 **7.1**	3 **50.0**
χ^2 Value = 12.59197	df = 4		p = .01345

greater category. The Rh(c) data falls into percentages resembling those assumed by the Rh(t) trace subjects, but to a less marked degree, as illustrated in Table 23. Given the smaller sample size and the contradictory results reported with the console data set, the cautions reported in the impressionistic interpretation of the trace chi-square arrays apply even more strongly to the console chi-square results.

Table 23

Chi-square Frequencies of Asymmetry in the Handedness Groups, 80% of AP (Console)

Measurement point: 80% # of cases per cell **Column %**	Handedness Groups Rh	 Rhl	 Lh
Left side greater	30 **61.2**	12 **85.7**	4 **66.7**
Right side greater	16 **32.7**	1 **7.1**	2 **33.3**
Both sides equal	3 **6.1**	1 **7.1**	0 **0.0**
χ^2 Value = 4.03370	df = 4		p = .40146

Despite the lack of significance, the graphs of the percentages of asymmetries (Figures 21, 23, & 25) show some of the same trends in changes between left and right asymmetries for the right-handed groups. Figures 22, 24, and 26 refer to proportions of brains that lack significant differences between the hemispheres.

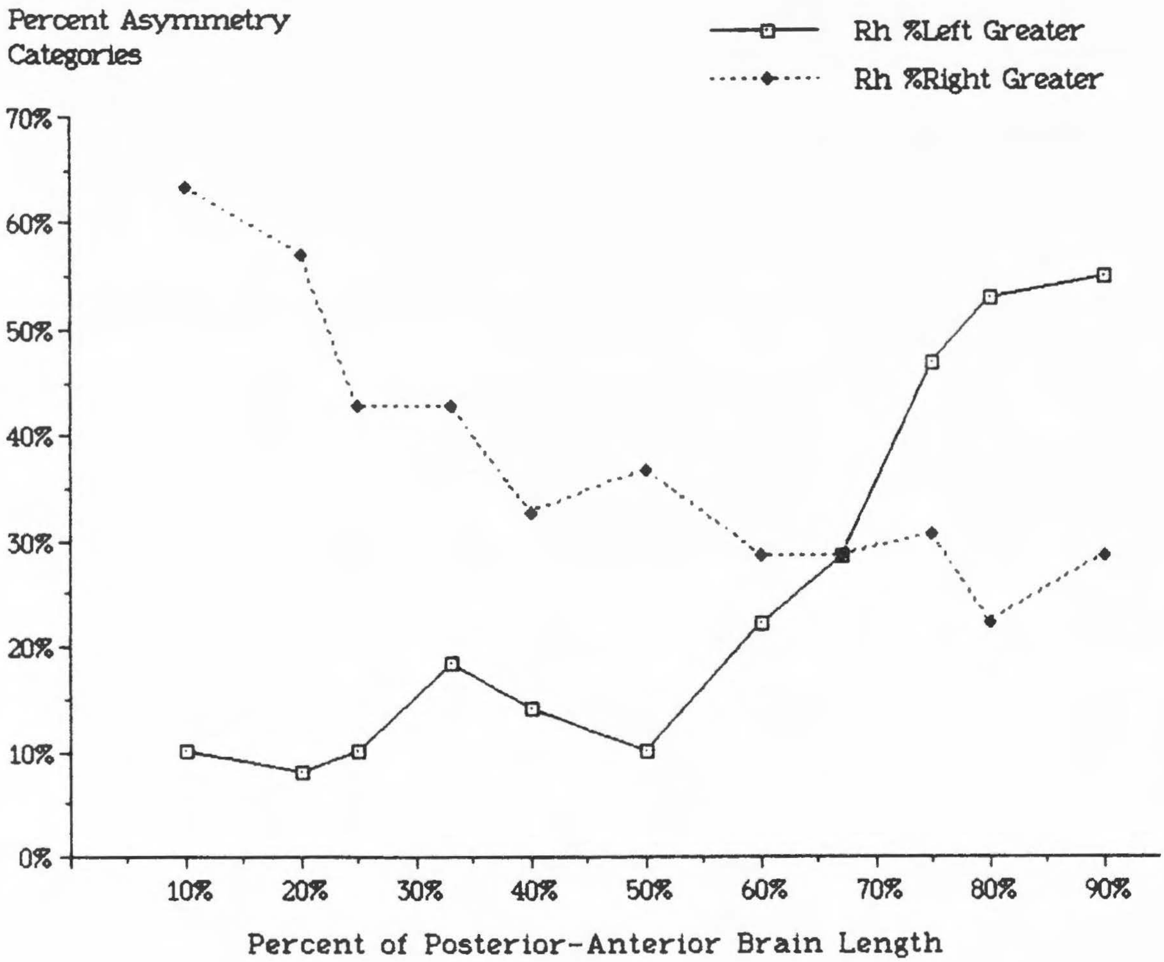


Figure 21. Percentages of left and right asymmetries for right-handed subjects, console data.

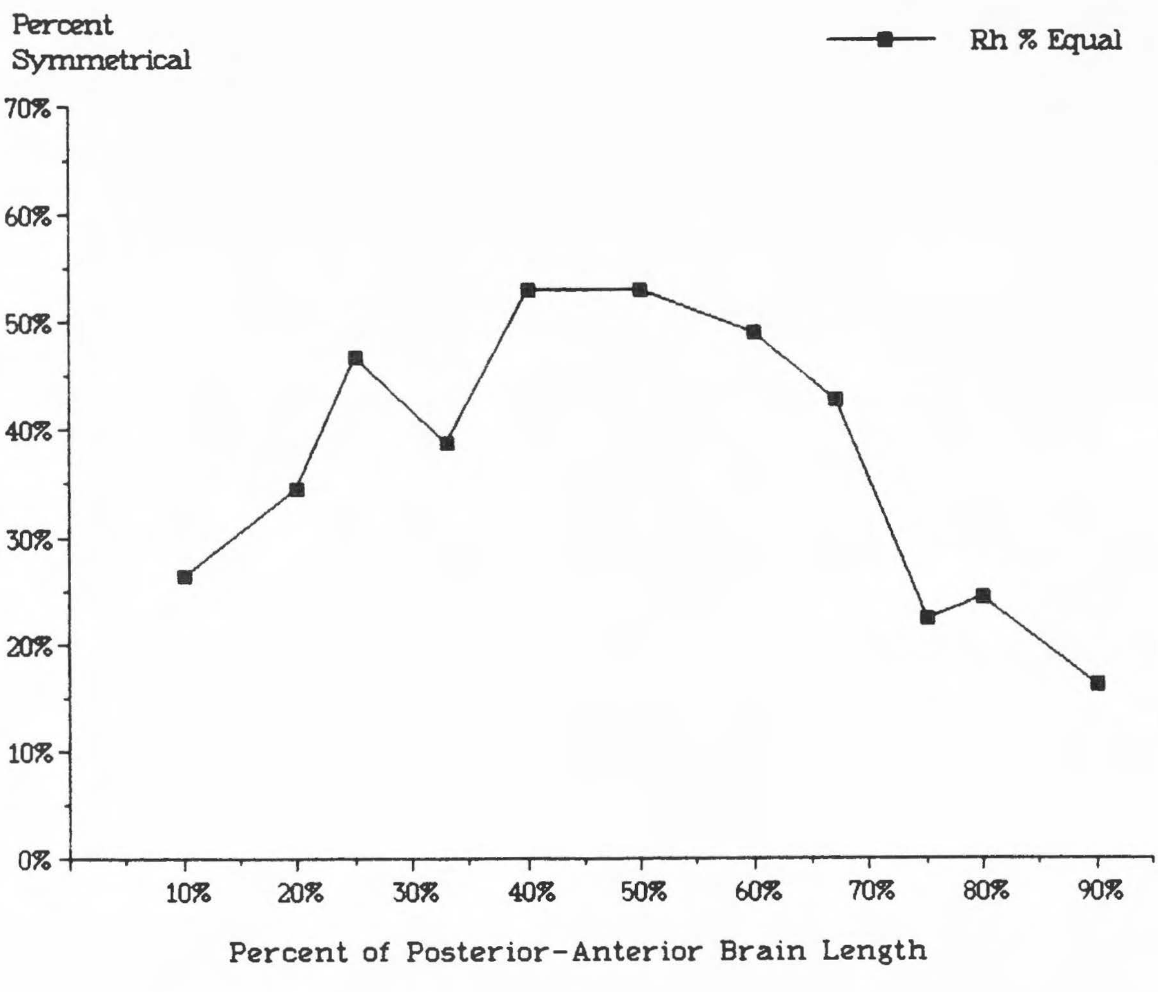


Figure 22. Percentages of symmetrical difference measures for right-handed subjects, console data.

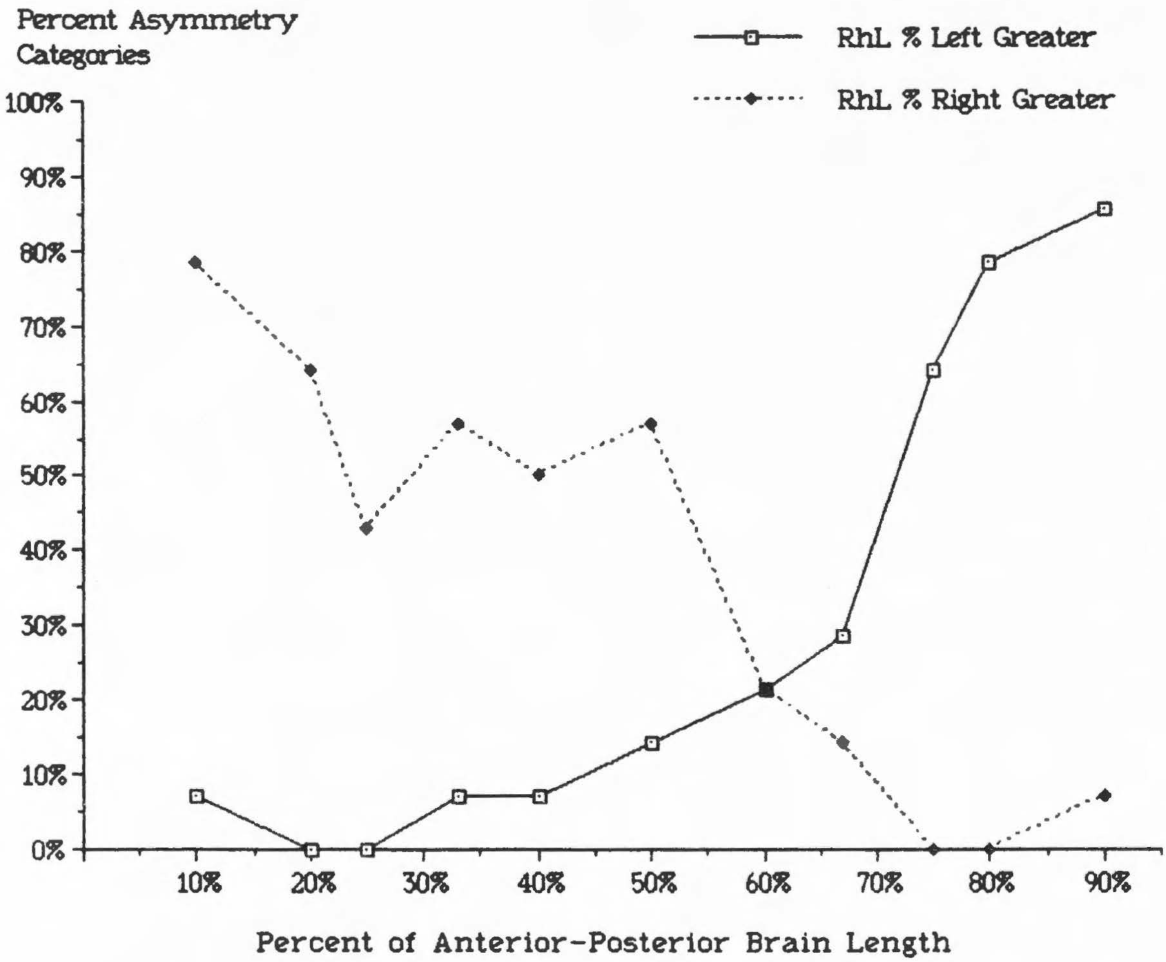


Figure 23. Percentages of left and right asymmetries for right-handed with left-handed relatives, console data.

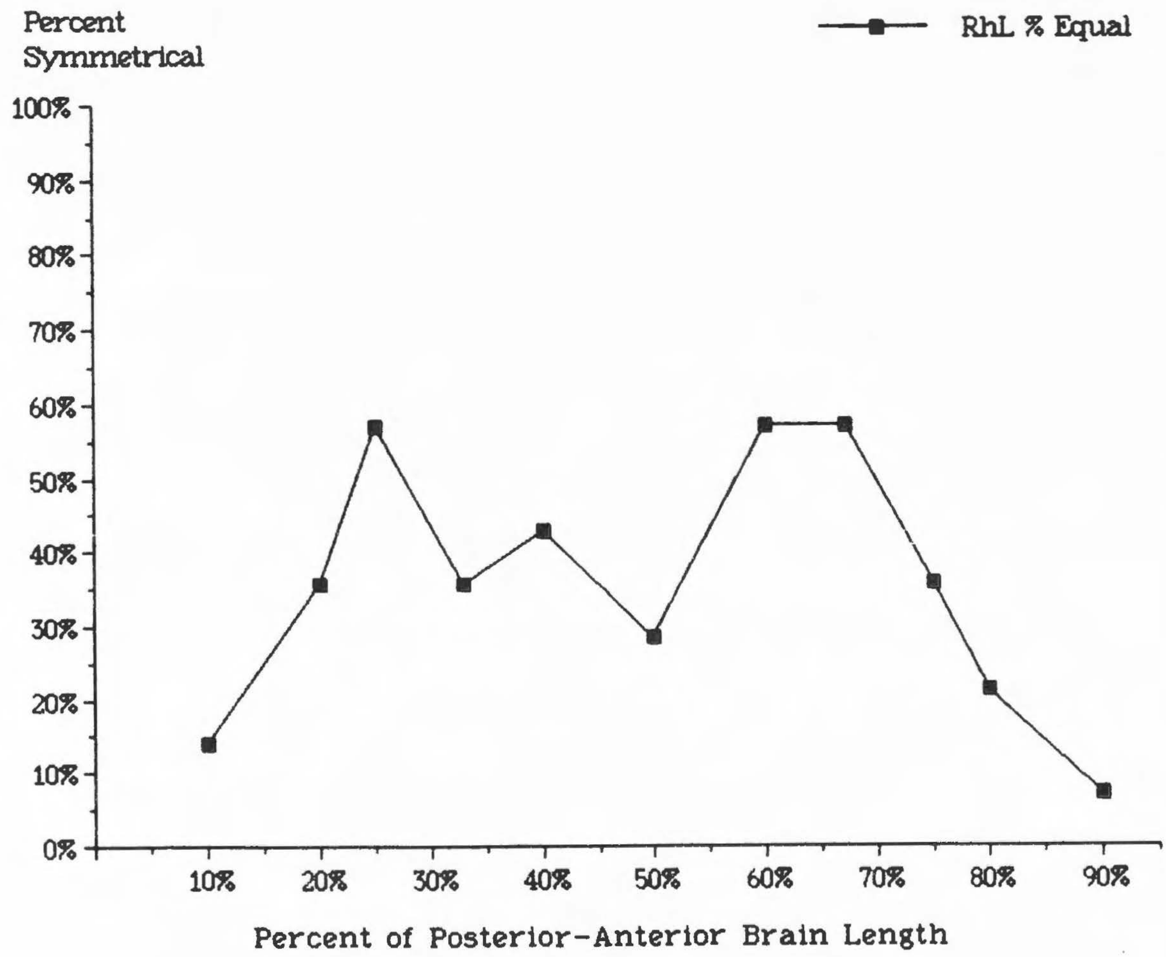


Figure 24. Percentages of symmetrical difference measures for right-handed with left-handed relatives, console data.

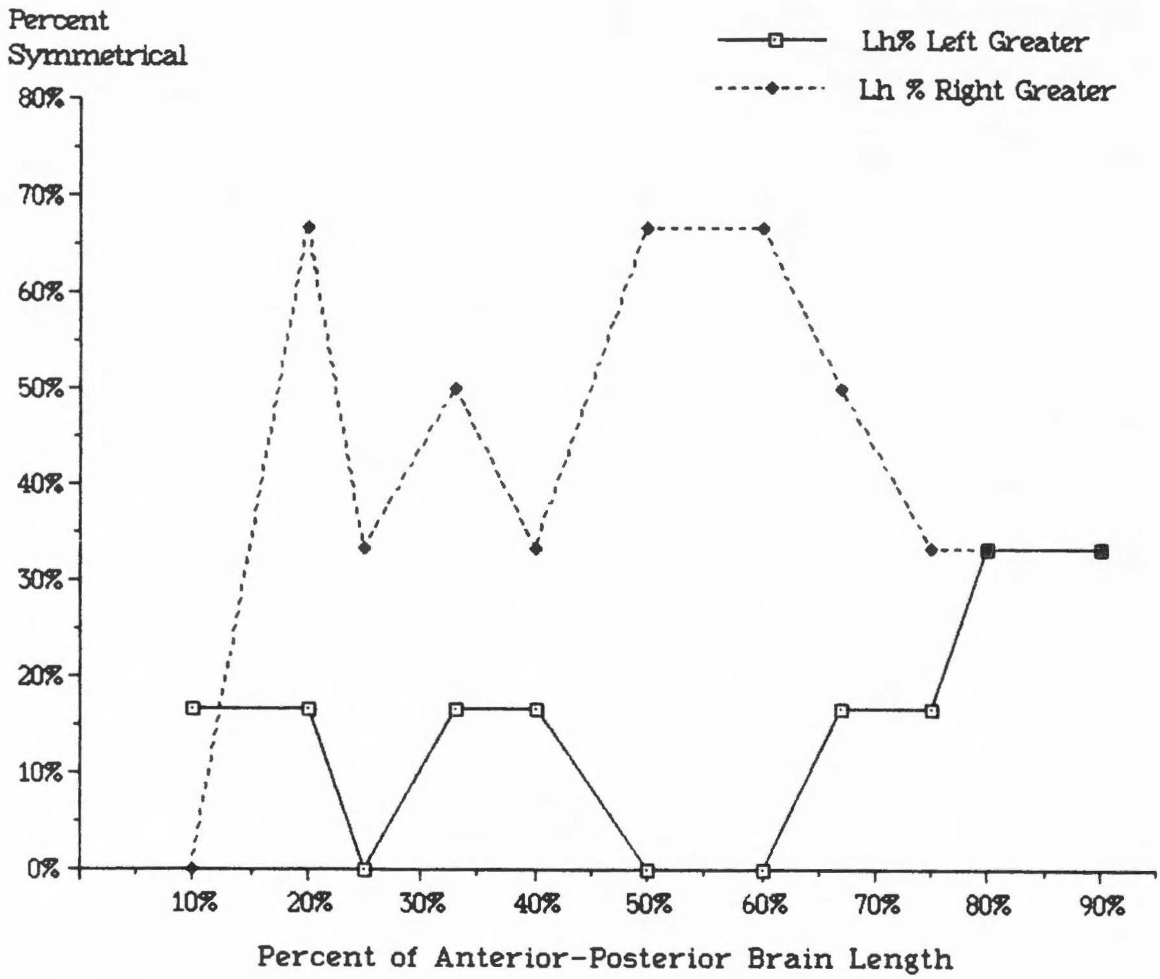


Figure 25. Percentages of left and right asymmetries for left-handed subjects, console data.

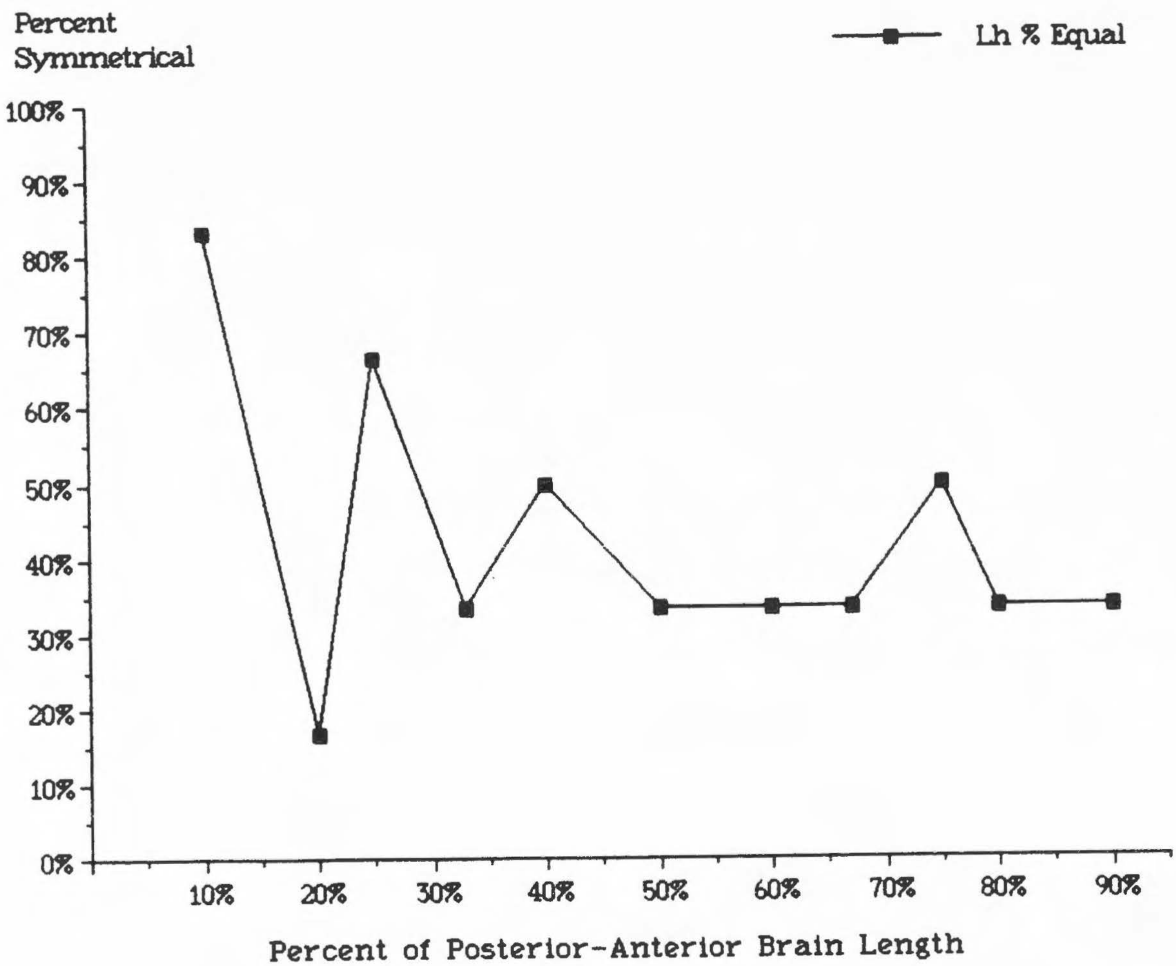


Figure 26. Percentages of symmetrical difference measures for left-handed subjects, console data.

Interactions Between Asymmetries at Anterior and Posterior Points of Opposite Hemispheres

To study the relation between asymmetries at the anterior and posterior regions of different hemispheres, subjects were categorized by combinations of asymmetries of given regions. Occipital asymmetries (L-R differences at 90%, 80%, and 75%) were combined into a single variable indicating asymmetry in the occipital lobe and the frontal measures (L-R differences at 25, 20, 10%) into a variable indicating asymmetry of the frontal lobe. The sum of occipital differences (SOCD) and sum of frontal differences (SFRD) were then used to assign brains into categories where particular combinations of asymmetries were observed. These categories are as follows:

1. Left > Right occipital/ Right > Left frontal (torque)
2. R > L occipital/L > R frontal (reversed torque)
3. L > R (L hemisphere larger in those 2 areas)
4. L occipital > R occipital/ L = R frontal
5. L < R (R hemisphere larger in those 2 areas)
6. R > L occipital/ L = R frontal
7. L = R occipital/ L < R frontal
8. L = R occipital/ L > R frontal
9. L = R occipital/L = R frontal (both hemispheres equal in these areas)

Type 1, where the left occipital and the right frontal lobes are larger, corresponds to the configuration that LeMay (1977) originally defined as torque. Other patterns include right occipital and left frontal larger (Type 2), a reversal of the putative average dominant pattern and the type to be studied as a contrast to the first. Symmetrical (left and right occipital and frontal lobes equal) and all other possible combinations were cross tabulated in a chi-square procedure and then grouped together into a global third category to avoid relying on an analysis in which the brains were divided into too many small groups. In a similar manner, the left-right differences at 67 and 60% of AP were combined into SPT (sum of posterior temporal), and the differences at 40 and 33% of AP were summed to make SFT (sum of frontal temporal) and used to perform a chi-square analysis to examine relations between the two areas of the brain that subserve different aspects of speech.

The results of the chi-square of the nine combinations of occipital/frontal asymmetries of the two hemispheres indicated that Type 1 is the leading pattern of asymmetry. This pattern was seen in 31, or 45.6%, of all right-handed subjects (right-handers with left-handed relatives were not included in this analysis). The next most common pattern is left occipital and left frontal wider (Type 3), characterizing 9, or 13.2%, of the right-handed subjects. None of the other patterns exceed 10% of the sample. The left-handed subjects are relatively evenly spread over five of the nine categories of asymmetry, and the remaining four categories being empty. Type 1 in the left-handed group accounts for 4, or 25%, of the subjects, and Type 5, right occipital and right frontal larger, is the pattern accounting for another 25% of the subjects; the remaining 8 subjects are spread more or less evenly among the other three categories. The chi-square is not significant. Types 3 through 9 were collapsed into one category, and the results can be seen in summary in Table 24.

Table 24

Chi-Square Frequencies of Linked Occipital/Frontal Asymmetry Types in Right- and Left-Handed Subjects

# of cases per cell **Row %**	Asymmetry Types Type 1 (torque)	 Type 2 (reversed torque)	 All others
Right hand	31 **45.6**	6 **8.8**	31 **45.6**
Left hand	4 **25.0**	3 **18.8**	9 **53.3**
χ^2 Value = 2.81801		df = 2	p = .24439

The relation between the posterior and anterior cortical areas, represented by the sums of percentage points 67 and 60 and 40 and 33, reveal no overwhelmingly predominating pattern in the right-handed group. The largest single pattern is one where the SPT (sum of posterior temporal) and SFT (sum of frontal temporal) are both larger on the left side of the brain. This characterizes 18, or 26.5%, of the right-handed subjects. None of the other patterns exceed 20% of the sample. The left-handed subjects are characterized by one interesting linked asymmetry, where SPT is larger on the right and SFT is equal in the right and left hemispheres (Type 5) in 7, or 43.8% of the left-handed subjects. None of the other categories in which there were subjects (7 out of 9) exceed 20%. The chi-square is not significant. Types 3 through 9 were collapsed into one category, and the results can be seen in summary in Table 25.

Table 25

Chi-Square Frequencies of Linked Posterior Temporal/Temporal Frontal Asymmetry Types in Right- and Left-handed Subjects

# of cases per cell	Asymmetry Types		
Row %	Type 1 (torque)	Type 2 (reversed torque)	All others
Right	11	6	51
Hand	**16.2**	**8.8**	**75.0**
Left	0	3	13
Hand	**0.0**	**18.8**	**81.3**
χ^2 Value = 3.84582		df = 2	p = .14618

At this juncture, it appears that no real conclusions can be drawn from these data about relations between asymmetries in different hemispheres.

Possible Confounds

Gender × Asymmetry Interactions

Research on rats (Diamond, 1984) suggests that males and females have cortical thickening at opposite sides of the brain during specific developmental periods. Humans also have some gender-related neurological differences, among them a 10 to 15% size disparity between males and females (Witelson & Kigar, 1987b). Given the suggested role of sex hormones in the development of lateralization and neuroanatomical asymmetry, it is logical to try to account for the gender factor in this study of neuroanatomical asymmetry and handedness.

Despite the very small number of males in Lh(t), an attempt was made to study the effect of gender in the magnitude of asymmetries in the trace and console data sets. Two-way ANOVA's were conducted on L-R difference scores by handedness category and gender. No significant main effects or interactions for gender and handedness were found at any of the 11 measurement points for trace data. The console data also show no main or interaction effects for gender.

A three-way analysis of L-R differences by Handedness, gender, and age category was highly desirable, but was not possible due to the small number of males in the left-handed group.

A different approach to the analysis of the possible differential influence of gender involved rerunning the one-way ANOVA tests with one gender only. For the males, no specific conclusions could be made due to the small *n* (two individuals) in the left-handed group. However, the results of the ANOVA's in the female-only comparisons appear more distinct than the results observed when the ANOVA's were carried out with mixed-gender handedness groups. The female Rh(t), Rhl(t), and Lh(t) *n*'s were 39, 14, and 14, respectively (only trace subjects were used in this particular case). In the comparison of right hemisphere widths by handedness group for females, the Lh(t) widths were greater than those of the right-handed subjects in the 90 to 50% measurement points. In other words, the earlier-reported finding of a larger posterior half of the right hemisphere in left-handers appears more strongly (and at a more stringent α level as well) in the female group. All other findings with the ratio and left-right differences were also replicated in the females-only analysis. These preliminary results suggest that comparable numbers of males and females are essential to the full study of neuroanatomical asymmetry. The males in the sample, while not significantly different from the females in the measurements taken in this study, appear to have a somewhat attenuating effect on the results. Further research is needed to determine if males have a higher proportion of anomolous patterns of neuroanatomical asymmetry.

Age × Asymmetry Interactions

The work of Diamond (1984; 1987) suggests an age factor in asymmetry in rats. Wada, Clarke, and Hamm (1975); Chi, Dooling, and Gilles (1977); and Witelson and Pallie (1973) have noted planum temporale asymmetries in infants in percentages and directions similar to those of adults. Geschwind and Galaburda (1987) cited other sources who have mapped planum temporale asymmetries in the brains of fetuses in the 31st week of gestation. Geschwind and Galaburda cited other studies that indicate that processes underlying neuroanatomical asymmetry also continue after birth. Logically, other processes may impact the development of neuroanatomical asymmetry later in the life span. As a result, it was thought necessary to investigate the possibility of Age × Asymmetry effects in the trace and console samples.

The ages of the subjects were categorized in such a way as to provide an adequate number of subjects in each age range. In the trace sample, the age groups were low through 23 (Age Group 1, n=17), 24 through 40 (Age Group 2, n=31) and 41 through high (Age Group 3, n=61). One-way ANOVA's were conducted for Age Group × L-R difference scores. No significant intergroup differences were found in asymmetries by age category. This procedure was repeated for the console subset of the data. In the console subset, Age Group 1 contained 11 subjects, Group 2 contained 20, and Group 3 contained 38. One F ratio obtained at measurement point 33 approached but did not surpass the .05 level with a p= .0509. The youngest age group (1) was recorded as having larger left hemispheres than the two older groups.

Two-way ANOVA's of handedness group by age category and L-R difference scores were also carried out. In the trace group, no significant main effects or Age × Handedness interactions were observed. The same analysis was carried out for the console subset. No significant main effects for age or Hand × Age category interactions were noted.

Alcohol Use × Asymmetries

The use of alcohol has a possible connection to neuroanatomical asymmetry. McShane and Willenbring (1984) found a greater degree of symmetry between the cerebral hemispheres in a sample of alcoholics compared to patients referred for CT scans who had no history of alcoholism. Geschwind and Galaburda (1987) cited researchers who report a higher incidence of left-handedness among alcoholics and others who report a lower degree of right-handedness (that is, less strongly right-handed) in alcoholics. Furthermore, there is evidence that alcohol has a preferential effect on the right hemisphere (Geschwind & Galaburda, 1987). It is possible that response to alcohol is different in those with anomolous patterns of neuroanatomical asymmetry. A question that may need to be asked is whether different hemispheric configurations are markers of risk for alcoholism or whether heavy and prolonged use of alcohol results in configurations resembling those in left-handers and anomolous right-handers. In the trace sample, 21 subjects stated that they use alcohol and 77 denied use (or were young children). The degree of alcohol use was not assessed in the questionnaire. In phone follow-ups, a small number of subjects did admit to a history of heavy use, with the majority of the subjects stating only occasional and light use of beverage alcohol. It is likely that the range of use among the subjects who do imbibe alcohol is quite wide. One-way ANOVA's were carried out on the subjects in the trace and console samples to study any observable effects of this variable. In an ANOVA of Alcohol use × L-R difference scores, no significant F ratios were noted at any of the levels of measurement. In the same procedure carried out on the console subset of the sample, no significant F's were generated.

CT Finding and Asymmetries

Insofar as CT studies involve patients referred for this radiological procedure, a higher proportion of pathology than in a nonhospital population is a logical expectation. Most of the previous studies, notably LeMay's (1977; LeMay & Kido, 1978), involved patients whose brain scans were described as showing nondistorting pathology, diffuse atrophy, and other signs of disease process. As stated in the method chapter, brain scans that evidenced major distorting pathology were screened out of the sample at the outset of the study. In the absence of actual access to the medical records of the patients, the author attempted to obtain a rough idea of positive findings (as opposed to the reason for referral) by asking the patients if they had been given their diagnoses and whether positive findings had been revealed by the scan. T tests were conducted in an attempt to determine if this variable differentiated in any way the brains of the subjects in the sample. In the trace data, no significant differences were found between the no-CT-finding and positive-CT-finding groups. The same lack of significant findings characterized the console subset.

Referral Question and Asymmetries

The referral question pertains to the reason, listed on the patient's film, for the scan. When the reason for referral was missing from the film, it was obtained from the appropriate questionnaire item. The referral question has some importance when one considers that some pathological processes (such as neoplasm) can have a profound effect on the contours of the brain. Other pathological conditions, such as immune disorders, vestibular and eye movement disorders, migraines, seizure and epileptic conditions, may have a connection with one handedness category or another (Geschwind & Galaburda, 1987). Headache was far and away the most common referral category, accounting for 35 of the trace subjects, followed by stroke (n=16) and head trauma (n=12). No other category had more than 8 subjects. Console data also listed headache as a leading category (n=21) followed by head trauma (n=0) and by a conglomerate category including dizziness and loss of balance, and/or muscular control (n=9) with no other category exceeding 7 in number. Despite the severe constraints that a large number of categories with small numbers of subjects might logically place on an ANOVA procedure, one-way ANOVA's were run for the trace and console measurements to investigate any possible effects of referral reason on asymmetry.

The Referral category × L-R difference score procedure for the trace set yielded no significant F ratios at any level of measurement. One F ratio (20% of AP, Fr3) approached but did not surpass the .05 level of significance with a p= .0626. Console results were similar in that no F ratio of the Referral question × L-R ratio ANOVA's were significant. One ratio approached but did not surpass the .05 level of significance with a p value of .0831.

Summary of Results

Individuals in the two right-handed groups had, on the average, smaller hemisphere widths in the right-posterior quadrant of the CT slice measured. Changes away from asymmetry toward symmetry in the left-handed group involved larger right-side measurements rather than a smaller left hemisphere. No significant differences were noted between groups in average anterior quadrant measurements, in contrast to the findings of other researchers (LeMay, 1977, LeMay & Kido, 1978). In terms of the ratios of left to right hemisphere ratio and left-right difference measures, both right-handed groups showed significant differences from the left-handed groups. Right-handers showed in four out of five occipital/temporal-parietal points a left greater-to-equal direction in ratio and difference measures, while left-handed subjects showed an equal-to-right greater direction at the same four points. The right-handed group with a positive history of family sinistrality [Rhl(t)] differed less markedly from the left-handed group (two out of five points in the same region) and did not significantly differ from the right-handers with a negative history for sinistrality at any ratio or difference measure. Correlations between adjacent measures in the area were moderate to strong, increasing the likelihood of an underlying relation among the measures.

When the brain asymmetries were categorized into left-greater, right-greater, and both-sides-equal classes, frequencies were found that were similar to those reported in other studies of frontal and occipital asymmetry (see Table 1). Three of the occipital and temporal/parietal chi-square comparisons were significant, with 75% of brain length indicating a left-side occipital asymmetry in the right-handed group and the 67 and 60% of brain length measures suggesting a right-side asymmetry in the left-handed group. Graphs of the data show the expected directions of difference in the right-handed groups and a more variable and irregular pattern in the left-handed group. Further categorization of the brains into groups where frontal and occipital asymmetries were linked (e.g., Type 1, occipital-left/frontal-right asymmetrical brains, Type 2, occipital-right/frontal-left asymmetrical brains, and all others) did not show significant associations between anterior and posterior hemispheric asymmetries. When similar procedures were applied to posterior-temporal/frontal-temporal areas, the results were equally inconclusive and nonsignificant.

CHAPTER V

DISCUSSION

The purposes of this study were to (1) investigate the relation between a given functional asymmetry, hand preference, and gross neuroanatomical asymmetries in the brain; (2) describe the asymmetries themselves and the interaction of asymmetries at different points at a given level of the brain; and (3) investigate the role of familial sinistrality on the expression of neuroanatomical asymmetry on a subgroup of the right-handed group. Asymmetries have been studied in relative isolation, and the form and relation of asymmetries at different points of the brain may give clues to the processes by which different brain functions are lateralized. An influential theory concerning the origin of handedness (Annett; 1987, 1978) suggests that dominance for speech and, secondarily, handedness results from a gene that interferes with right-hemisphere development. The homozygous recessive gene yields a condition where dominance for speech and, secondarily, handedness is random. Based on this, it was hypothesized that right-handers with a family history of left-handedness would have a higher probability of resembling the left-handed group in the manner in which the expression of neuroanatomical symmetry/asymmetry occurs.

Male and female subjects of wide age range receiving CT scans for medical reasons were contacted. They were questioned as to hand preference and family history of sinistrality, and their answers were used to classify the scans into handedness/family history groups. These data were then analyzed using analysis of variance, correlation coefficients, and chi-square.

Major Findings

In ANOVA's carried out on hemispheric widths (as measured from the midline defined in the measurement procedures) no significant differences were found in left-hemisphere widths by handedness groups. Significant differences were found in right-hemisphere widths by handedness groups, with left-handers having wider occipital/temporal measurements at 80, 75, and 60% of the AP line. These percentage points correspond roughly to visual association, visuo-auditory association, and auditory association cortex, which includes part of Wernicke's area. The right-handers with a positive history of left-handedness were significantly different from the left-handed group at 80 and 75% of the AP line.

The finding in left-handers of larger right-side measurements in three out of five posterior-right-hemisphere widths was somewhat startling in view of the literature on which this study was originally based. Geschwind and Behan (1982) and subsequently Geschwind and Galaburda (1985a, 1985b, 1985c, 1987) advanced what has become known as the "testosterone hypothesis." Based on observations of handedness and immune disease, migraine, developmental disorders, and other conditions Geschwind and Behan succinctly stated their hypothesis that testosterone is "a major influence that slows the growth of the convexity of the left hemisphere *in utero*" (1982, pp. 5099). In the later publications mentioned above, Geschwind and

Galaburda discussed the role of the right hemisphere in terms of "right hemisphere conservatism" (1987); where the swifter development of the right hemisphere, in contrast to the testosterone-retarded left, theoretically spares the right from influences to which the slower growing left is subject. They continued to to propose that:

> ...enlargement of left sided regions in response to disturbance of the developmental pattern of the right will be less common than the reverse situation, namely, larger size on the right as a result of left side delay and subsequent diminished cell death on the right. (1987, p. 45)

The presence of a number of larger posterior-right-hemisphere widths in the left-handed group combined with nonsignificant differences in the corresponding quadrant of the left hemisphere suggests that asymmetry and symmetry of the cerebral hemispheres do not arise in the manner proposed above. Instead of right-hemisphere widening occurring as a result of some form of corresponding diminution of the left hemisphere, the brains of left-handed subjects appear to have left-hemisphere widths comparable to those of the right-handed groups and larger right hemispheres in the posterior quadrant.

In an article reappraising the original study carried out by Geschwind and Levitsky (1968), Galaburda, Corsiglia, Rosen, and Sherman (1987) confirmed this finding in somewhat different terms. They re-examined the brains initially studied by Geschwind and Levitsky and replicated the basic finding of a larger left planum temporale (a part of Wernicke's area on a portion of the posterior Sylvian fissure) in 63% of the brains in the sample (with 21% of the plana larger on the right and 16% symmetrical). When the left and right plana combined was examined relative to the asymmetry of the plana, it was observed that the more asymmetrical the plana is in a leftward direction, the smaller the overall area of the combined left and right plana. In a similar manner, the brains of right-handers in the present study appear, at this general CT level, to have smaller posterior-right-hemispheres than the left-handers and comparable left hemispheres.

In a series of one-way ANOVA studies, the right- and left-hemisphere measurements were transformed into left÷right ratios and left-right differences. The ratios examined the differences in direction of relation between the cerebral hemispheres by handedness group, and the differences expressed the relation's size. In both the ratio and difference measure comparisons, the same four points of the AP line were associated with significant intergroup differences. These points included those already noted in the discussion of the right-hemisphere differences, that is, 80, 75, and 60% of AP, and a new significant comparisons observed at 67% of AP.

To reiterate the results reported in Chapter 4, the right-handed and left-handed groups were significantly different at all four of these points, and the right-handers with left-handed relatives were significantly different at two of these points. The right-handers with sinistral family history, then, were less different from the left-handers but not significantly different from right-handers lacking sinistral parents or siblings. Figures 11 and 13 illustrate the similarity between the two right-handed groups.

The graphs in Figures 11 and 13 also illustrate the changes in the measurements as a function of position on the AP line. The right-handed group is most asymmetrical in terms of ratios and differences at 90, 80, and 75% of AP (the left hemisphere being approximately 2.5 to 3 millimeters wider). At 67 and 60%, the ratios and differences between left and right drop close to equality of relation between the hemispheres. Meanwhile, the left-handed group measurements displayed a movement away from the point of equality. Starting above the line indicating equal ratios and no difference, the left-handed group's measurements moved below this line at 80% and decreased to their lowest point at 60% of AP. While the right-handed groups' interhemispheric measurements moved in the direction of equality, the left-handed group measurements moved in the direction of asymmetry of the right side. At this point (67 and 60% of AP), the left-handed groups' measurements could be said to be defining the asymmetries. While right-handed groups were more left asymmetrical in an area of visual association cortex (80 and 75%, arguably 90% as well), the left-handed group measurements moved in a right-asymmetrical direction that culminated in the auditory association cortex (Brodmann Area 21) in the posterior temporal lobe.

No other comparisons at more anterior points on the AP line in the temporal and frontal lobe areas were significant. The right-handed group's ratios stayed near the area of equality until the 33% point (an area approximately within Broca's area, Brodmann 44, 45), at which point the ratios and differences turned in a direction indicating a trend toward right-side asymmetry. At its greatest extent, at the 20 and 10% points, this rightward turn amounted to 1.00 to 1.70 millimeters and was virtually identical for all three handedness groups.

The relative enlargement of the left occipital lobe in right-handed subjects is a relatively robust finding in the literature and was confirmed here. The more equivocal nature of findings related to frontal-lobe asymmetry was also observed, in that a trend toward a wider right frontal lobe was noted, but did not in any way distinguish the three handedness groups. The shape of the graphed data did appear to suggest the phenomenon that LeMay (1977) describes as torque, an occipital left widening and an associated frontal-right widening. However, that relation in mean hemispheric ratios appeared not to follow the same pattern in the left-handed females who participated in this study.

The findings reported here extend those concerning the whole widths comparisons. The relatively smaller right hemisphere was observed in relation to a relatively wider left hemisphere in the right-handed group, and the right hemisphere in the left-handed group appeared to manifest a mean asymmetry at the 60% point and a relative asymmetry at the 67% point. The asymmetry at 60% was described by the writer as a mean asymmetry because the contrasting ratio and difference at that point for the right-handed group was, as described above, virtually identical with equality in terms of hemispheric measurements. Geschwind and Galaburda's (1987) review of asymmetry findings does not report a similar asymmetry in the temporal lobe. Many studies restrict measurement to a limited portion of the anterior and posterior ends of the brain. The findings here suggest a pattern to the asymmetries somewhat more complex than LeMay's torque. Actual linkage between asymmetries in a given brain was not specifically confirmed, but only suggested, by the graphs of the ratios and differences. The correlations between adjacent measures within the occipital/temporal area were moderate to strong across handedness groups. The frontal area correlations were less strong and somewhat variable between groups. A weak negative correlation was observed in the right-handed group between the occipital/temporal measures and the frontal measures, a finding in the direction of torque. However, the occipital to frontal measure correlations accounted for a small amount of the variance between the measurements and perhaps could be interpreted as a sign that linkage between the asymmetries of the occipital lobe and the formation of the frontal lobe have no obvious direct connection.

The last category of results to be discussed concerns the actual frequencies of artificially categorized asymmetries. The relatively small mean differences between groups and the large range of differences between individuals (as indicated by large standard deviations for the measurements) support the statement made by Geschwind and Galaburda that gross and fine neuroanatomical features are not adequately defined as either right or left asymmetrical or symmetrical, but rather as a range of graded asymmetries with as yet unknown qualitative and quantitative behavioral consequences. However, categorizing the findings in terms of right or left asymmetry and equality does permit the comparison of these findings with others in the literature.

When the right-handed group was examined for left asymmetries in the occipital area (90, 80, and 75% of AP), 61.8 to 63.2% of the brains are in that category. Right asymmetries at the same points of

AP were seen in 11.8 to 17.6% of the brains, and 20.6 to 26.5% were symmetrical. These comparisons were statistically significant only at 75% of AP, in all likelihood due to the relatively large number of comparisons being made in the chi-square procedure. Despite the lack of significance, comparing these results with those of other studies was instructive (see Table 1). It was at the 67 and 60% points that the left-side asymmetry percentages dropped below 60%. At these points, the left-handed group manifested the temporal lobe asymmetry referred to above. The chi-square comparisons carried out at the above the 67 and 60% points revealed that 62.5 to 56.3% of the left-handed group showed a right-side asymmetry at these points (10 and 9 of the 16 brains, respectively).

Insofar as the majority of the left-handed subjects in this study were female and a clinical population, a great deal of caution is advised in interpreting this finding. Other writers have noted that left-handers and those with left-handed relatives appear to have a better prognosis for recovery from aphasia, and Schachter and Galaburda (1986) cited a number of studies of CT asymmetries of aphasia patients associating atypical patterns of neuroanatomical asymmetry (most notably reversals) with improved recovery. The current data suggest a situation that is more complex than either less-marked asymmetry in left-handers or a greater proportion of reversals. Galaburda et al. (1987) speculated on a number of possible developmental scenarios, starting with the mechanism of the testosterone hypothesis that the language substrates develop initially asymmetrically but can emerge in a more symmetrical pattern due to later environmental factors during fetal development and infancy. In these speculations, the authors are mainly talking about a highly circumscribed area of the brain. However, the conceptual framework may be useful in the discussion of the current findings. Testosterone, as mentioned above, is thought to slow the development of the left hemisphere in certain individuals, leading to corresponding regions on the right to grow larger and thus decreasing asymmetry. In another scenario, the system could be at the outset symmetrical, and developmental factors could lead to the paring down of one side and the relative growth of the other. Yet another possibility (starting from an assumption that the system is initially asymmetrical) could be that a majority of brains (asymmetrical) would grow until reaching the adult pattern, while a smaller number of brains would undergo a process whereby the larger side loses cells until it matches the other. Or, in an initially symmetrical system, an atypical brain grows up to a point and then stops, and a majority pattern brain continues to grow on one side. The authors wrote:

> Symmetry, by these two possibilities, would represent a failure of the dominant side to grow and/or remain larger, and the relationship between symmetry and asymmetry would be expressed as....the greater the degree of asymmetry, the greater the combined amount of language substrate (left plus right). (pg. 860)

The third developmental pattern speculated by these authors again begins by assuming an asymmetrical system. After this beginning point, the brain can grow at the same rate on both sides and remain in that state, or one of the sides continues to grow and, as it were, catches up to the other to yield a symmetrical brain. The converse situation would be one wherein a symmetrical brain grows to a given size and then stops, and then one side loses tissue and becomes smaller:

> Symmetry, then, would represent a failure of the non dominant side to grow smaller and/or remain smaller, and ....In this relationship, the greater degree of asymmetry, the lesser the total amount of language substrate (left plus right). (pg. 861)

Galaburda et. al (1987) found results consistent with the last possibility in their reanalysis of Geschwind and Levitsky's (1968) original data. In the present study, left-handers appeared to have a larger posterior portion of the right hemisphere than right-handers. It would appear that something similar to this scenario may apply to the entire back half of the right hemisphere. The results of this study support a reexamination of the testosterone hypothesis.

When an attempt was made in this study to raise the question of the relation of asymmetries in one hemisphere to distant, rather than adjacent, parts of the next hemisphere, the results were inconclusive. Categorization of the brains into groups where frontal and occipital asymmetries were linked (occipital left/frontal right asymmetrical brains, occipital right/frontal left asymmetrical brains, and other patterns) did not show significant associations between anterior and posterior hemispheric asymmetries. When similar procedures were applied to posterior temporal/frontal temporal areas, the results were equally inconclusive and nonsignificant. It is of interest that the largest single pattern found in right-handers (45.6%) suggests an association between a wider right frontal lobe and wider left occipital lobe. However, that finding cannot be used to conclude that there is a significant relation between asymmetries in the frontal and occipital lobe.

It is of interest that there is no apparent correspondence between temporal widths in the approximate area of auditory association cortex and right-handedness. Apparently, the left asymmetry of the planum temporale (located above the plane of section on the brain employed in this study) in relation to right-handedness that has been abundantly documented in other studies is not related to temporal-lobe widening at points below.

One of the key questions that may be lurking in the background of any reader of this research report could be: Why is there a relation, however modest, between handedness and neuroanatomical asymmetry patterns? This question is especially pertinent in view of the relative distance of the CT slice in question from cerebral cortex in the primary motor area normally considered to mediate hand movements. A speculation that may be offered here takes into account the relatively large amount of motor and association cortex devoted to the production of speech. It is proposed that hand preference (which is a graded characteristic) is an epiphenomenon of the intensive commitment of a given hemisphere to the production and comprehension of speech. This would result in a relatively large number of individuals with strong predispositions to developing right-hand preference, a second group where equality of hemisphere widths implies duplication of structure further and implies chance and environmental determination of hand preference, and a smaller group where a strong predisposition exists toward left-hand preference due to a relative preponderance of right-hemisphere tissues. This speculation is not specifically contradicted by most of the genetic theories of the origin of handedness. The asymmetry noted in the right-handed groups in secondary visual association cortex could be an added weight in the equation of factors pointing toward the development of handedness. An asymmetry of visual association cortex could have a role in the development of skilled motor activities in right-handers. The association of left- and mixed-handedness with superiority in tasks involving both hands (Kilshaw & Annett, 1983) could be related to a relatively larger total amount of secondary visual association cortex. The posterior temporal lobe asymmetry noted in this study in left-handers is also interesting in view of the anecdotal association between left-handedness and musical talent.

Yet another issue that may arise on viewing the findings here relates to a lack of significant frontal lobe asymmetries. Although frontal asymmetries are reported by LeMay (1977, LeMay & Kido, 1978), this finding has been much less robust and has not been noted by other researchers or in this study. Again, only speculation can be offered as to the lack of frontal lobe asymmetry. Lezak (1983) described the frontal lobes as more recent in an evolutionary sense than most other areas of the brain, and also as not being characterized by lateralization for functional abilities to the same extent as other areas. The most frequently noted lateralized problem associated with damage to the frontal lobes is Broca's, or expressive, aphasia. Areas forward of the secondary motor cortex associated with speech production are often described as uncommitted cortex, although that designation fails to hint at the integration of sensory and motor systems that underlie the most uniquely human aspects of behavior. Perhaps lateralization is less characteristic of the final stages of processing that occurs in the frontal lobes, which take the output of the other parts of the brain responsible for organizing the input of the senses and mediate their translation into behavior. It is worth noting, however, that McShane (1987) found significant correlations between frontal and temporal width asymmetries and WAIS-R subtest scores (specifically picture arrangement), that scores were higher with a wider left-frontal lobe, and that verbal subtests appeared to have a positive relation to wider temporal measurements (specifically at 60% of AP). It is possible that more precise measures of asymmetry and more pure measures of verbal and nonverbal abilities will find stronger relations between asymmetry and ability.

Summary

The results of this study suggest that neuroanatomical asymmetry (differences in hemispheric width by percentage of AP line) is moderately related to hand preference. Familial sinistrality in right-handed subjects does not distinguish a subgroup of dextrals from others with a negative record for left-handed relatives. It is possible that right-handers with left-handed relatives are more similar to left-handers without being significantly different from right-handers lacking sinistral first-degree relatives. However, such a conclusion cannot be drawn from the present results.

Individuals in the two right-handed groups had, on the average, smaller hemisphere widths in the right-posterior quadrant of the CT slice measured. Consistent with the findings of Galaburda, Corsiglia, Rosen, and Sherman (1987), changes away from asymmetry toward symmetry in the left-handed group involve larger right side measurements rather than a smaller left hemisphere as originally suggested in Geschwind and Galaburda's original testosterone hypothesis (1985a, 1985b, 1985c, 1987). No significant differences were noted between groups in average anterior-quadrant measurements, in contrast to the findings of other researchers (LeMay, 1977, LeMay & Kido, 1978). In terms of the ratios of left to right hemisphere ratio and Left-Right difference measures, both right-handed groups showed significant differences from the left-handed group. Right-handers (group 1) showed in four out of five occipital/temporal-parietal measures a left greater-to-equal direction in ratio and difference measures, while left-handed subjects showed an equal-to-right greater direction at the same four points. The right-handed group with a positive history of family sinistrality (group 2) differed less markedly from the left-handed group (2 out of 5 points in the same region described above) and did not significantly differ from the right-handers with a negative history for sinistrality at any ratio or difference measure. Correlations between adjacent measures in the area were moderate to strong, increasing the likelihood that there is an underlying relation among the measures.

When the brain asymmetries were categorized into left-greater, right-greater, and both-sides-equal classes, frequencies were found that were similar to those reported in other studies of frontal and occipital asymmetry (see Table 1). However, only three of the occipital and temporal/parietal chi-square comparisons were significant, possibly due to insufficient numbers of subjects. Graphs of the data show the expected directions of difference in the right-handed groups and a more variable and irregular pattern in the left-handed group. The frequencies observed support the position that hand preference and neuroanatomical asymmetry, as measured in this study, are only moderately related. A novel finding in this study was that of right-hemisphere asymmetry in left-handers in the posterior end of the temporal lobe.

The relatively small mean differences between groups and the large range of differences between individuals (as indicated by relatively large standard deviations for the measurements) support the statement made by Geschwind and Galaburda that gross and fine neuroanatomical features are not adequately defined as either right or left asymmetrical or symmetrical but rather as a range of graded asymmetries with as yet unknown qualitative and quantitative behavioral consequences. Handedness, for all its diverse aspects and definitions, is just one marker for these graded asymmetries.

Limitations and Suggestions for Future Research

There are a number of important limitations in this study. The wide range of ages and small number of young subjects precluded the use of three-way analyses with other variables (gender) that could have an impact on the development of neuroanatomical asymmetries. The important role of hormones involved in sexual differentiation strongly suggest that there is a degree of sexual dimorphism on a neuroanatomical level. The overwhelming ratio of females to males in the left-handed sample combined with a small *n* likewise prevented the study of age and gender variables in a group that was known to be anomalous in many other aspects. The almost all-female composition of the left-handed group also prevented generalization of the observations made to males. Despite the lack of gross distorting pathology, the sample was set apart from the average population in that they were drawn from a medical setting. The family-history variable was probably too generously defined and would be better based on a performance measure of first-degree relatives. When based on stated preference alone, the history of family sinistrality is compromised by family size (very simply, the higher the number of children, the higher the probability that one or more will be left-handed). Due to the multifactoral nature of handedness (Healey, Liederman, & Geschwind, 1986), the addition of a handedness instrument that compares the actual performance of each hand on particular tasks would be a very important addition to studies of this kind (an example is the assessment technique developed by Tapley & Bryden, 1985). Lacking a performance measure, it would have been advantageous to have a handedness inventory with more easily comprehended instructions. Strength of preference (and/or performance) may in fact be the variable that family history of sinistrality, in this study, was not, i.e., a factor with a mediating role in the relation between handedness and neuroanatomical asymmetry.

One possible distorting variable that was not conclusively dealt with in this study concerns variability in the angulation of any given patient's head while that patient was receiving a CT scan. The CT technician assisting this researcher responded to a question of impact of angle of patient's head on accuracy of the scan that the algorithm used by the computer to construct the image could deal with the problem adequately. If distortion does indeed occur, an argument could be made that there is no reason to assume that head tilt is more likely to occur in one direction more often than another. In that event, the interference of any distortion from angulation could be manifested as noise, a moderating influence on the results.

The small *n* also prevented conclusive statements about the question of relation between asymmetries. This question, important to investigating the development of the physical basis of lateralization, requires sufficient numbers of subjects to differentiate among the nine possible patterns of relations (when investigating the relation between the two areas on two hemispheres) between the two sets of asymmetries studied.

Future research could involve the use of more precise measurement techniques with more carefully defined subject variables. Kertesz (1988) and Kertesz, Black, Polk, and Howell (1986), are apparently engaged in large scale research with normal (not referred for medical evaluation) subjects measured on a magnetic resonance imaging device, which is reputed to have better resolution than a CT scanner. Kertesz and colleagues also have gathered a great deal of data on a number of functional abilities for potential correlation with asymmetries. The use of normal subjects without medical problems is an important step in the study of these phenomena, as is the ability to have a detailed picture of individual characteristics (including a multifaceted picture of the many different ways in which a person is lateralized). Considering that a new asymmetry is suggested by the research reported here, a suggestion for future research would be, simply, to take continuous measurements along the contours at a given level of the brain and to attend to issues of the relation of asymmetry to area for the light that can be shed on developmental issues. When notion that the brain is symmetrical, though lateralized for abilities, was replaced by the notion that the brain is asymmetrical and lateralized, researchers turned to these deviations from symmetry for ideas as to how structure relates to function. This research seems to indicate that the details of how that structure varies and the rules underlying it are far from specified.

Chi, J. G., Dooling, E. C., & Gilles, F. H., (1977). Gyral development of the human brain. Annals of Neurology, 1, 86-93.

Chui, H. C., & Damasio, A. R. (1980). Human cerebral asymmetries evaluated by computer tomography. Journal of Neurology, Neurosurgery, and Psychiatry, 43, 873-878.

Collins, R. L. (1985). On the inheritance of direction and degree of asymmetry. In S. D. Glick (Ed.), Cerebral lateralization in nonhuman species (pp. 41-72). Orlando, FL: Academic Press.

Corballis, M. C. (1983). Human laterality. New York, NY: Academic Press.

Corballis, M. C., & Morgan, M. J. (1978). On the biological basis of human laterality: I. Evidence for a maturational left-right gradient. Behavioral and Brain Sciences, 2, 261-336.

Coren, S., & Porac, C. (1977). Fifty centuries of right handedness: The historical record. Science, 198, 631-632.

Denenburg; V. H., (1981). Hemispheric laterality in animals and the effects of early experience. Behavioral and Brain Sciences, 4, 1-49.

Deuel, R. K., & Moran, C. C. (1980). Cerebral dominance and cerebral asymmetries on computed tomograms in children. Neurology, 42, 934-938.

Diamond M. C., (1984). Age, sex, and environmental influences. In N. Geschwind, & A. M. Galaburda (Eds.), Cerebral dominance: The biological foundations (pp. 134-146). Cambridge, MA.: Harvard University Press.

Diamond M. C., (1987). Asymmetry in the cerebral cortex: Development, estrogen receptors, neuron/glial ratios, immune deficiency and enrichment/overcrowding. In D. Ottoson (Ed.), Duality and unity of the brain: Unified functioning and specialization of the hemispheres (pp. 37-52). London, GB: The MacMillan Press LTD.

Filskov, S. B., & Locklear, E. (1982). A multidimensional perspective on clinical neuropsychology research. In P.C. Kendall, & J. N. Butcher (Eds.), Handbook of research methods in clinical psychology (pp. 651-674). New York, NY: Wiley-Interscience.

Galaburda, A. M., Corsiglia, J. , Rosen, G. D., & Sherman, G. F., (1987). Planum temporale asymmetry, reappraisal since Geschwind and Levitsky. Neuropsychologica, 25(6), 853-868.

Galaburda, A. M., LeMay, M., Kemper, T. L., & Geschwind, N. (1978). Right-left asymmetries in the brain. Science, 199, 852-856.

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

Geschwind, N., & Behan, P. (1984). Laterality, hormones, and immunity. In N. Geschwind, & A. M. Galaburda (Eds.), Cerebral dominance: The biological foundations. (pp. 211-224). Cambridge, MA.: Harvard University Press.

Geschwind, N., & Galaburda, A. M. (1984). Cerebral dominance: The biological foundations. Cambridge, MA: Harvard University Press.

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

Geschwind, N., & Galaburda, A. M. (1985b). Cerebral lateralization. Biological mechanisms, associations, and pathology: Part II. Archives of Neurology, 42, 521-552

Geschwind, N., & Galaburda, A. M. (1985c). Cerebral lateralization. Biological mechanisms, associations, and pathology: Part III. Archives of Neurology, 42, 632-654

Geschwind, N., & Galaburda, A. M. (1987). Cerebral lateralization. Cambridge, MA: M. I. T. Press.

Geschwind, N., & Levitsky, W. (1968). Human brain: Left-right asymmetries in temporal speech region. Science, 161, 186-187.

Glick, S. D. (1985). Cerebral lateralization in nonhuman species. New York, NY: Academic Press.

Hamilton, C. R. (1977) An assessment of hemispheric specialization in monkeys. Annals of the New York Academy of Science, 299, 222-232.

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

Herron, J. (1980). Neuropsychology of left handedness. New York, NY: Academic Press.

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

Hicks, R. E., & Kinsbourne, M. (1978). Human handedness. In M. Kinsbourne, (Ed.), Asymmetrical function of the brain (pp. 523-549). New York, NY: Cambridge University Press.

Hier, D., LeMay, M., & Rosenberger, P. (1978). Developmental dyslexia: Evidence of a subgroup with a reversal of cerebral asymmetry. Archives of Neurology, 35, 90-92.

Hochberg, F. H., & LeMay, M. (1974). Arteriographic correlates of handedness. Neurology, 25, 218-222.

Kertesz, A. (1988). Is language prewired in the brain? Journal of Neurolinguistics, 3(1), 29-37.

Kertesz, A., Black, S. E., Polk, M., & Howell, J. (1986). Cerebral asymmeties on magnetic resonance imaging. Cortex, 22, 117-127.

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

Kilshaw, D., & Annett, M. (1983). Right and left handed skill: I. Effects of age, sex, and hand preference showing superior skill in left handers. British Journal of Psychology, 74, 253-268.

LeMay, M. (1976). Morphological cerebral asymmetries of modern man, fossil man, and nonhuman primates. Annals of the New York Academy of Sciences, 280, 349-366.

LeMay, M. (1977). Asymmetries of the skull and handedness: Phrenology revisited. Journal of the Neurological Sciences, 32, 343-353.

LeMay, M. (1985). Asymmetries in the brains and skulls of nonhuman primates. In S. D. Glick, (Ed.), Cerebral lateralization in nonhuman species (pp. 234-246). New York, NY: Academic Press.

LeMay, M., & Culebras, A. (1972). Human brain morphological differences in the hemispheres demonstrated by carotid angiography. New England Journal of Medicine, 287, 168-170.

LeMay, M., & Kido, D. K. (1978). Asymmetries of the cerebral hemispheres on computed tomograms. Journal of Computer Assisted Tomography, 2, 471-476.

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

Lezak, M. D. (1983). Neuropsychological assessment. New York, NY: Oxford University Press.

Loftus, G. R., & Loftus, E. F. (1982). Essence of statistics. Monterey, CA: Brooks/Cole.

Luria, A. R. (1970). Traumatic aphasia. The Hague: Mouton.

Maccoby, E. M., & Jacklin, C. N. (1974). The psychology of sex differences. CA: Stanford University Press.

MacNeilage, P. F. (1987). The evolution of handedness in primates. In D. Ottoson (Ed.) Duality and unity of the brain: Unified functioning and specialization of the hemispheres (pp. 100-113). London, GB: The MacMillan Press LTD,.

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

McMeekan, E. R. L., & Lishman, W. A. (1975) Retest reliabilities and interrrelationship of the Annett hand preference questionnaire and the Edinburgh handedness inventory. British Journal of Psychology, 66, 53-59.

McRae, D. L., Branch, C. L., & Milner, B. (1968). The occipital horns and cerebral dominance. Neurology, 18, 95-98.

McShane, A. (1987). A study of the relationships between hemispheric asymmetries and intellectual abilities. Unpublished master's thesis, Utah State University, Logan, Utah.

McShane, D. (1983). Neurocranial Form: Differentiating four ethnic populations using a simple CT scan measure. International Journal of Neuroscience, 21, 137-144.

McShane, D., Risse, G. L., & Rubens, A. B. (1984). Cerebral asymmetries on CT scans in three ethnic groups. International Journal of Neuroscience, 23, 69-74.

McShane, D., & Willenbring, M. L. (1984). Differences in cerebral asymmetries related to drinking history and ethnicity. Journal of Nervous & Mental Disease, 172, 529-532.

Nachshon, I., & Denno, D. (1987). Birth stress and lateral preferences. Cortex, 23, 45-58.

Nottebohm, F., & Nottebohm, M. (1976). Left hypoglossal dominance in the control of canary and white crowned sparrow song. Journal of Comparative Physiology, 108, 171-192

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

Ratcliff, G., Dila, L., & Tayler, L. (1980). The morphological asymmetry of the hemispheres and cerebral dominance for speech: A possible relationship. Brain and Language, 11, 87-98.

Satz, P. (1980). Incidence of aphasia in left handers: A test of some hypothetical models of speech organization. In J. Herron (Ed.), Neuropsychology of left handedness. New York: Academic Press.

Schacter, S. C., & Galaburda, A. M. (1986). Development and biological associations of cerebral dominance: Review and possible mechanisms. Journal of the American Academy of Child Psychiatry, 25(6), 741-750.

Springer, S. P., & Deutsch, G. (1985). Left brain, right brain. New York, NY: Freeman & Company.

Strauss, E., & Fitz, C. (1980). Occipital horn asymmetry in children. Annals of Neurology, 8, 437-439.

Tapley, S. M., & Bryden M. P., (1985). A group test for the assessment of performance between the hands. Neuropsychologica, 26, 215-221.

Tsai, L. Y., Nasrallah, H. A., & Jacoby, C. G. (1983). Hemispheric asymmetries on computed tomographic scans in schizophrenia and mania. Archives of General Psychiatry, 40, 1286-1289.

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

Witelson, S. F., & Kigar, D. L., (1987a). Individual differences in the anatomy of the corpus callosum: Sex, hand preference, schizophrenia and hemisphere specialization. In A. Glass (Ed.), Individual differences in hemispheric specialization (pp. 55-92). New York, NY: Plenum Press.

Witelson, S. F., & Kigar, D. L., (1987b). Neuroanatomical aspects of hemisphere specialization in humans. In D. Ottoson (Ed.) Duality and unity of the brain: Unified functioning and specialization of the hemispheres (pp. 466-495). London, GB: The MacMillan Press LTD.

Witelson, S. F., & Pallie, W., (1973). Left hemisphere specialization for language in the newborn: Neuroanatomical evidence of asymmetry. Brain, 96, 641-646.

Wittig, M. A., & Petersen, A. C., Eds. (1979). Sex related differences in cognitive function. New York, NY: Academic Press.

Satz, P. (1980). Incidence of aphasia in left handers: A test of some hypothetical models of speech organization. In J. Herron (Ed.), Neuropsychology of left handedness. New York: Academic Press.

Schacter, S. C., & Galaburda, A. M. (1986). Development and biological associations of cerebral dominance: Review and possible mechanisms. Journal of the American Academy of Child Psychiatry, 25(6), 741-750.

Springer, S. P., & Deutsch, G. (1985). Left brain, right brain. New York, NY: Freeman & Company.

Strauss, E., & Fitz, C. (1980). Occipital horn asymmetry in children. Annals of Neurology, 8, 437-439.

Tapley, S. M., & Bryden M. P., (1985). A group test for the assessment of performance between the hands. Neuropsychologica, 26, 215-221.

Tsai, L. Y., Nasrallah, H. A., & Jacoby, C. G. (1983). Hemispheric asymmetries on computed tomographic scans in schizophrenia and mania. Archives of General Psychiatry, 40, 1286-1289.

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

Witelson, S. F., & Kigar, D. L., (1987a). Individual differences in the anatomy of the corpus callosum: Sex, hand preference, schizophrenia and hemisphere specialization. In A. Glass (Ed.), Individual differences in hemispheric specialization (pp. 55-92). New York, NY: Plenum Press.

Witelson, S. F., & Kigar, D. L., (1987b). Neuroanatomical aspects of hemisphere specialization in humans. In D. Ottoson (Ed.) Duality and unity of the brain: Unified functioning and specialization of the hemispheres (pp. 466-495). London, GB: The MacMillan Press LTD.

Witelson, S. F., & Pallie, W., (1973). Left hemisphere specialization for language in the newborn: Neuroanatomical evidence of asymmetry. Brain, 96, 641-646.

Wittig, M. A., & Petersen, A. C., Eds. (1979). Sex related differences in cognitive function. New York, NY: Academic Press.

APPENDICES

Appendix A

Protocol for Telephone Interview

When there has been no response from the potential subject within two weeks from the mailing date, the research assistant will telephone the potential subject and follow the following procedure:

1. When the telephone is answered at the residence of the subject, the research assistant should ask: "Is this the________residence? Could I speak with________?" (If the subject is a child, or you have been informed that the subject is unable to answer the questions or is deceased, ask to speak to a parent, caretaker, or nearest relative.)

2. The research assistant will then identify him/herself by saying: "I am________and I am working on the brain study research with Dr McShane from Utah State University and Logan Regional Hospital".

3. Then the assistant asks: "Did You receive a mailing recently regarding this study?"

3a. If NO, then verify the address of the subject, and tell him/her that a mailing will be sent to them and request that s/he review the mailing and send back the consent form and questionnaire, if applicable. Answer the subjects questions. Send out a mailing to the subjects' verified address. Record this contact information on the mailing card (date, time, mailing not rec., new mailing sent, date).

3b. If YES, ask: "Did you read the materials and are you interested in participating in the study? (Go to 4)

If NO, thank the person for their time and record "NON PARTICIPANT" on the mailing card.

4. Ask the subject if s/he wishes to participate further in the research. Say, "please look at the consent form, which is the second page of the mailing. Which level of participation are you willing to be involved in?" Read each level to the subject from the consent form, using the exact wording of the form. When the subject responds, ask him/her to mark that item and return the form in the self-addressed envelope. Put "level____subject" on the mailing card.

5. If this subject received the <u>first</u> form of the questionnaire, carry out steps 1 and 2 and say: "I have some additional questions which were not included in the first questionnaire. Could you answer them for me now?" Fill in the numbered questionnaire addendum with the subjects or caregiver's answers.

Appendix B

Questionnaire for Brain Asymmetry Study

ID# ________________

Please complete the following questionnaire to the best of your knowledge. If this letter was addressed to a child, a caretaker (parent, or other) may complete the questionnaire. If you are not sure of some of the answers, you may inquire of family members to assist in completing the questionnaire. Thank you!

Age: ___________

Sex (Please circle one): Male Female

Occupation (If applicable): ____

Person completing questionnaire: ____________________________(self, parent, spouse, other)

1. Please indicate which hand you use to perform the following activities by putting a + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless forced to, put ++. If you use both hands to perform the task, put + in both columns. Please try to answer all the questions. If you are completing this for your child, observe the child if possible.

Self or child Biological Father Biological

Mother

Task:	Right:	Left:	Right:	Left:	Right:	Left:
1. Writing	_____	_____	_____	_____	_____	_____
2. Drawing	_____	_____	_____	_____	_____	_____
3. Throwing	_____	_____	_____	_____	_____	_____
4. Scissors	_____	_____	_____	_____	_____	_____
5. Toothbrush	_____	_____	_____	_____	_____	_____

2. If you are an adult, please give your best guess on the handedness of each of your biological brothers and sisters. If you are completing this for a child, give your best guess on the handedness of the child's brothers and sisters. Please circle the sex of the sibling (M=male, F=female) and the hand used most by that sibling.

Sex of Sibling:		Handedness:	(please circle)
M	F	Left	Right
M	F	Left	Right
M	F	Left	Right
M	F	Left	Right
M	F	Left	Right
M	F	Left	Right
M	F	Left	Right
M	F	Left	Right

4. Please name the condition or problem that lead your doctor to recommend a CT scan:

____

____

____

5. Please name or describe what your doctor told you had been found by the CT scan (the problem or condition):

____

____

____

6. Do you drink alcoholic beverages (beer, wine, liquor)? ______________________

____

Thank you very much for your cooperation!

Note: This questionnaire contains only those questions that pertain to this study. The actual questionnaire contains more questions that have not been shown here.

Appendix C

Cover Letter and Insert (on Logan Regional Hospital Letterhead)

Dear:_________

Dr. Damian McShane of the Department of Psychology at Utah State University, in collaboration with the Department of Radiology at Logan Regional Hospital, is conducting a research study concerning the relationships between the left and right sides of the brain. Dr. McShane (Principle Investigator) is working with CT scans personnel here at the hospital, as well as with CT personnel at sites in Florida, New Jersey, California, Japan, and Europe, in order to find individuals who may be able and be interested in participating in this international study.

Many human brains show an interesting characteristic; they are usually larger on one side than the other. Some scientists have thought that this interesting organization in the structure of the brain may be related to the fact that the brain tends more to use its left side for certain purposes (like language or to analyse a sequence of events), while the brain may tend to rely on its right half in doing other things (like art, music, or thinking about several things at the same time). Some people seem to be better at mentally doing things which tend to rely on the left side of the brain, while other people may be somewhat better at doing certain things depending upon the right half of the brain. The question that some have asked is whether the brains of those individuals who function well on "right-sided" tasks aren't a little larger on the right side, and whether the brains of those who function well on "left sided" tasks aren't a little larger on the left. In addition, this study is asking whether these patterns change or are different with respect to age, gender, or what hand a person prefers to use.

Therefore, Dr. McShane is interested in finding individuals who already have had CT scans (x-ray pictures) taken of their head and who would be willing to participate in the study. Agreement to participate in the study could be given at three different levels, depending on your interest and availability. Please check the appropriate box on the attached page and sign and return to Brain Study, c/o Department of Radiology, Logan Regional Hospital, 1400 North 500 East, Logan, Utah 84321 in the enclosed, self addressed stamped envelope. Your participation in this study would be confidential and no information which would identify participants will be released or used in reporting the results of the study. If you have any questions, feel free to call Dr. McShane at 750-1251 between 8:30 - 9:30 a.m., Monday through Friday.

Respectfully,

Ernest Rendon

Radiology Department Manager

<u>Insert</u>

If the person to whom this is addressed is a child, deceased, or is not capable of completing the questionnaire, it would be very helpful if a family member, spouse, or caretaker could provide any information you have about this person on the enclosed questionnaire. Your assistance with this project is greatly appreciated.

Appendix D

Consent Form Included with Questionnaire and Cover Letter

___ I do not wish to participate in this study by supplying information in any of the ways descibed below.

___ I would be willing to fill out the attached questionnaire and send it to you for use in the research study. (Please fill out next page and mail back with this form.)

___ I would be willing to fill out the attached questionnaire and to be interviewed over the telephone (for about 10 minutes) concerning such things as hand preference, whether I am good at art or good with words or other abilities. (fill out form, mail back, indicate tele.ph. number here: ___ - _________).

___ I would be willing to fill out the attached questionnaire, be interviewed over the telephone for about ten minutes, and take some brief tests which would involve an hour and a half and show whether I was better at doing "right-sided" tasks or "left sided" tasks (for instance, remembering some words versus doing a puzzle). (Please fill out form, mail back, and indicate tele.ph. number here: ___ - _________).

___ I am interested in getting the results of the study based on my participation.

_______________________ signature   _______________ date

ID# _______________

Appendix E — Tables

Table E1

Descriptive Statistics of the Measurement Variables for the Trace Sample, Console Subset, and the Three Handedness Groups

All trace subjects (n=108)

Variable Name	Mean Ratio L÷R	SD	SE	Min.	Max	Range
O1*	1.119	.259	.025	.455	2.375	1.920
O2	1.047	.099	.009	.772	1.270	.498
O3	1.043	.089	.008	.833	1.286	.452
O4	1.007	.060	.006	.742	1.160	.418
TP2*	.996	.053	.005	.750	1.138	.388
TP3	.987	.047	.005	.884	1.143	.259
TP4	.992	.055	.005	.883	1.366	.483
F1*	1.002	.069	.007	.857	1.350	.493
F2	.984	.096	.009	.706	1.758	1.052
F3	.977	.080	.008	.702	1.350	.648
F4	.953	.200	.019	.000	1.391	1.391
AP*	186.288	9.386	.891	166.000	207.000	41.000

Console measurement subjects (n=69)

Variable Name	Mean Ratio L÷R	SD	SE	Min.	Max	Range
O1	1.073	.152	.018	.730	1.423	.693
O2	1.045	.081	.010	.863	1.227	.363
O3	1.028	.068	.008	.880	1.216	.336
O4	1.001	.043	.005	.905	1.145	.241
TP2	.994	.038	.005	.892	1.079	.187
TP3	.985	.033	.004	.909	1.100	.191
TP4	.984	.045	.005	.887	1.091	.204
F1	.982	.043	.005	.864	1.063	.198
F2	.974	.042	.005	.877	1.106	.229
F3	.958	.048	.006	.875	1.119	.244
F4	.921	.097	.012	.667	1.129	.462
AP	185.043	8.148	.981	169.000	204.000	35.000

(tables continued)

Table E1 (continued)

Trace right-handers (n=68)

Variable Name	Mean Ratio L÷R	SD	SE	Min.	Max	Range
O1	1.137	.234	.028	.686	1.889	1.203
O2	1.060	.099	.012	.772	1.270	.498
O3	1.057	.090	.011	.863	1.286	.423
O4	1.016	.062	.008	.742	1.160	.418
TP2	1.005	.056	.007	.750	1.138	.388
TP3	.994	.048	.006	.894	1.143	.249
TP4	.998	.062	.008	.893	1.366	.473
F1	1.009	.076	.009	.887	1.350	.463
F2	.990	.113	.014	.706	1.758	1.052
F3	.978	.087	.011	.702	1.350	.648
F4	.949	.194	.024	.000	1.391	1.391
AP	185.853	9.765	1.184	167.000	206.000	39.000

Left-right ratios console, right-handers (n=49)

Variable Name	Mean Ratio L÷R	SD	SE	Min.	Max	Range
O1	1.055	.153	.022	.730	1.423	.693
O2	1.032	.079	.011	.863	1.196	.333
O3	1.018	.068	.010	.880	1.216	.336
O4	1.002	.047	.007	.905	1.145	.241
TP2	.995	.041	.006	.892	1.079	.187
TP3	.989	.032	.005	.909	1.100	.191
TP4	.987	.045	.006	.887	1.091	.204
F1	.988	.042	.006	.897	1.063	.166
F2	.973	.044	.006	.877	1.106	.229
F3	.968	.049	.007	.875	1.119	.244
F4	.920	.100	.014	.667	1.129	.462
AP	184.918	8.953	1.279	169.000	204.000	35.000

(tables continued)

Table E1 (continued)

Trace right-handers with left-handed relatives (n=24)

Variable Name	Mean Ratio L÷R	SD	SE	Min.	Max	Range
O1	1.121	.316	.065	.833	2.375	1.542
O2	1.049	.096	.020	.860	1.214	.354
O3	1.042	.081	.017	.907	1.213	.305
O4	1.006	.053	.011	.917	1.109	.192
TP2	.991	.040	.008	.905	1.052	.147
TP3	.976	.043	.009	.903	1.036	.133
TP4	.979	.045	.009	.883	1.071	.188
F1	.989	.064	.013	.857	1.167	.310
F2	.970	.066	.014	.797	1.077	.280
F3	.971	.067	.014	.840	1.075	.235
F4	.966	.148	.030	.629	1.214	.586
AP	187.542	9.722	1.985	166.000	207.000	41.000

Console right handers with left-handed relatives (n=14)

Variable Name	Mean Ratio L÷R	SD	SE	Min.	Max	Range
O1	1.165	.111	.030	.947	1.333	.386
O2	1.109	.072	.019	.982	1.227	.245
O3	1.067	.059	.016	.981	1.160	.179
O4	1.004	.030	.008	.935	1.034	.098
TP2	1.000	.031	.008	.937	1.049	.113
TP3	.978	.039	.010	.913	1.061	.148
TP4	.971	.050	.013	.903	1.089	.186
F1	.964	.046	.012	.864	1.038	.174
F2	.970	.039	.010	.893	1.021	.128
F3	.946	.044	.012	.891	1.022	.131
F4	.891	.087	.023	.743	1.056	.313
AP	186.714	5.312	1.420	175.000	195.000	20.000

(tables continued)

Table E1 (continued)

Trace left-handers (n=16)

Variable Name	Mean Ratio L÷R	SD	SE	Min.	Max	Range
O1	1.024	.269	.067	.455	1.500	1.045
O2	.987	.088	.022	.846	1.182	.336
O3	.980	.074	.018	.833	1.120	.287
O4	.968	.047	.012	.881	1.048	.168
TP2	.963	.042	.011	.859	1.033	.174
TP3	.978	.049	.012	.884	1.063	.179
TP4	.988	.033	.008	.906	1.049	.143
F1	.994	.047	.012	.911	1.059	.148
F2	.978	.048	.012	.893	1.060	.167
F3	.979	.068	.017	.796	1.093	.297
F4	.952	.292	.073	.000	1.231	1.231
AP	187.188	6.988	1.747	176.000	199.000	23.000

Console left-handers (n=6)

Variable Name	Mean Ratio L÷R	SD	SE	Min.	Max	Range
O1	1.011	.159	.065	.818	1.212	.394
O2	1.007	.060	.024	.930	1.087	.157
O3	1.014	.071	.029	.938	1.143	.205
O4	.990	.032	.013	.954	1.035	.081
TP2	.969	.021	.008	.941	1.000	.059
TP3	.973	.022	.009	.951	1.000	.049
TP4	.987	.029	.012	.952	1.036	.084
F1	.979	.036	.015	.944	1.038	.036
F2	.987	.032	.013	.941	1.020	.078
F3	.966	.047	.019	.915	1.042	.127
F4	1.001	.033	.013	.971	1.063	.091
AP	182.167	6.494	2.651	173.000	192.000	19.000

*O1-4= Occipital measurement ratios.

*TP2-4= Temporal/Parietal measurement ratios.

*F1-4= Frontal measurement ratios.

*AP= Anterior-Posterior measurement

(table continued)

Table E1 (continued)

Trace subjects (n=108) total brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TBW90	58.147	8.513	.815	32.000	80.000	48.000
TBW80	95.055	6.202	.594	80.000	112.000	32.000
TBW75	107.174	6.669	.639	91.000	123.000	32.000
TBW67	120.018	6.025	.577	103.000	134.000	31.000
TBW60	124.817	6.264	.600	106.000	136.000	30.000
TBW50	123.275	6.187	.593	105.000	136.000	31.000
TBW40	114.945	6.639	.636	95.000	129.000	34.000
TBW33	108.138	7.181	.688	86.000	126.000	40.000
TBW25	101.972	5.855	.561	87.000	116.000	29.000
TBW20	94.211	5.719	.548	81.000	110.000	29.000
TBW10	60.908	12.331	1.181	2.000[1]	89.000	87.000

Console subjects (n=69) whole brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CBW90	67.696	6.585	.793	52.000	85.000	33.000
CBW80	99.464	5.918	.712	86.000	116.000	30.000
CBW75	110.623	6.385	.769	94.000	126.000	32.000
CBW67	122.232	6.653	.801	98.000	138.000	40.000
CBW60	126.710	6.456	.777	101.000	140.000	39.000
CBW50	124.594	5.794	.697	114.000	137.000	23.000
CBW40	116.362	5.336	.642	104.000	130.000	26.000
CBW33	109.449	6.211	.748	94.000	126.000	32.000
CBW25	103.493	4.907	.591	93.000	114.000	21.000
CBW20	96.014	5.733	.690	84.000	116.000	32.000
CBW10	66.145	10.698	1.288	2.000	82.000	80.000

(table continued)

[1] 2.00 is a constant. At this measure, there was a missing value.

Table E1 (continued)

Trace right-handed subjects (n=68) total brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TBW90	56.809	8.027	.973	32.000	80.000	48.000
TBW80	94.559	5.956	.722	80.000	108.000	28.000
TBW75	106.515	6.591	.799	91.000	120.000	29.000
TBW67	119.500	6.020	.730	103.000	131.000	28.000
TBW60	124.235	6.179	.749	106.000	136.000	30.000
TBW50	122.750	6.087	.738	105.000	136.000	31.000
TBW40	114.441	6.252	.758	95.000	127.000	32.000
TBW33	107.618	6.563	.796	88.000	122.000	34.000
TBW25	101.544	5.804	.704	87.000	116.000	29.000
TBW20	93.765	5.163	.626	83.000	106.000	23.000
TBW10	59.647	12.993	1.576	2.000	89.000	87.000

Console right-handed subjects (n=49) whole brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CBW90	66.469	6.341	.906	52.000	84.000	32.000
CBW80	98.857	6.021	.860	86.000	116.000	30.000
CBW75	109.959	6.406	.915	94.000	126.000	32.000
CBW67	121.816	7.085	1.012	98.000	138.000	40.000
CBW60	126.347	6.882	.983	101.000	140.000	39.000
CBW50	124.633	5.798	.828	114.000	137.000	23.000
CBW40	116.347	5.414	.773	107.000	130.000	23.000
CBW33	109.551	5.986	.855	99.000	123.000	24.000
CBW25	103.388	5.057	.722	93.000	114.000	21.000
CBW20	96.020	6.139	.877	84.000	116.000	32.000
CBW10	65.061	12.111	1.730	2.000	82.000	80.000

(table continued)

Table E1 (continued)

Trace right-handed w/left rel. (n=24) total brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TBW90	59.625	7.689	1.569	44.000	80.000	36.000
TBW80	94.542	6.262	1.278	80.000	104.000	24.000
TBW75	107.000	6.574	1.342	91.000	119.000	28.000
TBW67	119.750	5.589	1.141	104.000	130.000	26.000
TBW60	124.792	6.029	1.231	106.000	133.000	27.000
TBW50	122.875	6.368	1.300	108.000	133.000	25.000
TBW40	114.208	7.396	1.510	97.000	127.000	30.000
TBW33	108.458	8.521	1.739	86.000	126.000	40.000
TBW25	102.042	5.607	1.144	91.000	111.000	20.000
TBW20	94.792	6.909	1.410	81.000	110.000	29.000
TBW10	64.000	8.985	1.834	47.000	84.000	37.000

Console right-handed with left-handed relatives (n=14) whole brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CBW90	69.786	4.870	1.302	62.000	80.000	18.000
CBW80	101.286	4.858	1.298	92.000	109.000	17.000
CBW75	112.286	5.413	1.447	103.000	123.000	20.000
CBW67	123.929	5.240	1.400	115.000	133.000	18.000
CBW60	128.429	5.214	1.394	121.000	139.000	18.000
CBW50	124.857	6.597	1.763	116.000	136.000	20.000
CBW40	116.071	5.929	1.584	104.000	126.000	22.000
CBW33	109.214	8.011	2.141	94.000	126.000	32.000
CBW25	103.786	5.117	1.368	97.000	114.000	17.000
CBW20	95.571	5.095	1.362	87.000	104.000	17.000
CBW10	68.714	5.567	1.488	61.000	80.000	19.000

(table continued)

Table E1 (continued)

Trace left handed subjects (n=16) total brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TBW90	60.625	10.417	2.604	32.000	75.000	43.000
TBW80	96.875	5.841	1.460	84.000	106.000	22.000
TBW75	109.250	6.050	1.512	100.000	122.000	22.000
TBW67	121.313	5.986	1.496	110.000	132.000	22.000
TBW60	126.625	6.551	1.638	113.000	136.000	23.000
TBW50	125.625	6.043	1.511	112.000	135.000	23.000
TBW40	117.500	6.460	1.615	107.000	129.000	22.000
TBW33	109.000	7.248	1.812	91.000	120.000	29.000
TBW25	103.188	6.442	1.610	89.000	113.000	24.000
TBW20	94.625	5.932	1.483	83.000	104.000	21.000
TBW10	60.938	13.680	3.420	28.000	78.000	50.000

Console left handed subjects (n=6) whole brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CBW90	72.833	9.131	3.728	60.000	85.000	25.000
CBW80	100.167	7.305	2.982	91.000	110.000	19.000
CBW75	112.167	8.329	3.400	104.000	124.000	20.000
CBW67	121.667	6.218	2.539	115.000	130.000	15.000
CBW60	125.667	5.538	2.261	120.000	133.000	13.000
CBW50	123.667	4.412	1.801	119.000	130.000	11.000
CBW40	117.167	3.656	1.493	113.000	122.000	9.000
CBW33	109.167	3.656	1.493	105.000	115.000	10.000
CBW25	103.667	3.670	1.498	99.000	110.000	11.000
CBW20	97.000	4.000	1.633	90.000	101.000	11.000
CBW10	69.000	5.292	2.160	60.000	74.000	14.000

(table continued)

Table E1 (continued)

Trace subjects (n=108) left side brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TL90	30.339	5.398	.517	10.000	45.000	35.000
TL80	48.505	3.800	.364	40.000	59.000	19.000
TL75	54.596	3.923	.376	44.000	66.000	22.000
TL67	60.156	3.512	.336	46.000	68.000	22.000
TL60	62.229	3.555	.341	48.000	70.000	22.000
TL50	61.202	3.176	.304	53.000	68.000	15.000
TL40	57.202	3.410	.327	47.000	65.000	18.000
TL33	54.055	3.913	.375	42.000	63.000	21.000
TL25	50.459	3.452	.331	36.000	58.000	22.000
TL20	46.477	3.450	.330	39.000	57.000	18.000
TL10	29.670	7.576	.726	.000	47.000	47.000

Console subjects (n=69) left brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CL90	34.855	3.964	.477	27.000	43.000	16.000
CL80	50.754	3.595	.433	42.000	60.000	18.000
CL75	56.014	3.829	.461	44.000	63.000	19.000
CL67	61.130	3.577	.431	48.000	69.000	21.000
CL60	63.130	3.464	.417	49.000	70.000	21.000
CL50	61.826	3.092	.372	56.000	70.000	14.000
CL40	57.681	2.993	.360	50.000	65.000	15.000
CL33	54.203	3.288	.396	46.000	62.000	16.000
CL25	51.043	2.741	.330	45.000	57.000	12.000
CL20	47.072	2.840	.342	40.000	55.000	15.000
CL10	31.667	5.754	.693	1.000	41.000	40.000

(table continued)

Table E1 (continued)

Trace right handed subjects (n=68) left side brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TL90	29.838	4.609	.559	17.000	40.000	23.000
TL80	48.515	3.513	.426	40.000	56.000	16.000
TL75	54.618	3.844	.466	44.000	66.000	22.000
TL67	60.221	3.656	.443	46.000	67.000	21.000
TL60	62.235	3.738	.453	48.000	70.000	22.000
TL50	61.132	3.162	.383	53.000	68.000	15.000
TL40	57.103	3.177	.385	47.000	64.000	17.000
TL33	53.956	3.526	.428	42.000	63.000	21.000
TL25	50.382	3.574	.398	40.000	54.000	14.000
TL20	46.265	3.281	.398	40.000	54.000	14.000
TL10	29.015	7.720	.936	.000	47.000	47.000

Console right handed subjects (n=49) left brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CL90	33.918	3.741	.534	27.000	42.000	15.000
CL80	50.122	3.539	.506	42.000	60.000	18.000
CL75	55.429	3.910	.559	44.000	63.000	19.000
CL67	60.939	3.870	.553	48.000	69.000	21.000
CL60	62.980	3.677	.525	49.000	70.000	21.000
CL50	61.959	3.048	.435	56.000	68.000	12.000
CL40	57.776	3.043	.435	52.000	65.000	13.000
CL33	54.408	3.214	.459	48.000	62.000	14.000
CL25	50.980	2.912	.416	45.000	57.000	12.000
CL20	47.184	2.949	.421	40.000	55.000	15.000
CL10	31.122	6.412	.916	1.000	41.000	40.000

(table continued)

Table E1 (continued)

Trace right-hand with left-handed relatives (n=24) left side brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TL90	31.042	4.814	.983	20.000	40.000	20.000
TL80	48.333	4.167	.851	42.000	55.000	13.000
TL75	54.542	4.107	.838	48.000	62.000	14.000
TL67	60.000	3.162	.645	54.000	66.000	12.000
TL60	62.083	3.229	.659	53.000	67.000	14.000
TL50	60.667	3.226	.658	54.000	67.000	13.000
TL40	56.458	3.822	.780	49.000	62.000	13.000
TL33	53.917	4.951	1.011	42.000	63.000	21.000
TL25	50.167	3.130	.639	44.000	56.000	12.000
TL20	46.667	3.996	.816	39.000	57.000	18.000
TL10	31.333	3.378	1.098	22.000	43.000	21.000

Trace left handed subjects (n=16) left side brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TL90	30.688	8.260	2.065	10.000	45.000	35.000
TL80	48.063	3.820	.955	40.000	52.000	12.000
TL75	54.000	3.559	.890	48.000	61.000	13.000
TL67	59.625	3.052	.763	53.000	65.000	12.000
TL60	62.063	3.214	.803	55.000	67.000	12.000
TL50	62.063	3.130	.782	56.000	67.000	11.000
TL40	58.375	3.403	.851	53.000	65.000	12.000
TL33	54.313	3.825	.956	45.000	61.000	16.000
TL25	51.000	3.521	.880	44.000	57.000	13.000
TL20	46.750	3.276	.819	41.000	53.000	12.000
TL10	29.625	9.715	2.429	.000	40.000	40.000

(table continued)

Table E1 (continued)

Trace subjects (n=108) right side brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TR90	27.807	5.069	.486	15.000	40.000	25.000
TR80	46.550	3.915	.375	37.000	57.000	20.000
TR75	42.000	4.128	.395	42.000	62.000	20.000
TR67	59.862	3.495	.335	50.000	68.000	18.000
TR60	62.587	3.536	.339	53.000	71.000	18.000
TR50	62.073	3.656	.350	52.000	70.000	18.000
TR40	57.743	3.814	.365	41.000	66.000	25.000
TR33	54.083	4.078	.391	40.000	64.000	24.000
TR25	51.514	3.668	.351	33.000	60.000	27.000
TR20	47.734	3.423	.328	39.000	57.000	18.000
TR10	31.239	5.921	.567	1.000	42.000	41.000

Console subjects (n=69) right brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CR90	32.841	4.182	.502	24.000	44.000	20.000
CR80	48.710	3.511	.423	42.000	57.000	15.000
CR75	54.609	3.507	.422	48.000	64.000	16.000
CR67	61.101	3.557	.428	50.000	70.000	20.000
CR60	63.580	3.440	.414	52.000	73.000	21.000
CR50	62.768	3.069	.369	57.000	69.000	12.000
CR40	58.681	2.958	.356	52.000	65.000	13.000
CR33	55.246	3.367	.405	48.000	66.000	18.000
CR25	52.449	2.649	.319	47.000	60.000	13.000
CR20	48.942	3.329	.401	42.000	61.000	19.000
CR10	34.478	5.484	.660	1.000	41.000	40.000

(table continued)

Table E1 (continued)

Trace right handed subjects (n=68) right side brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TR90	26.971	5.223	.633	15.000	40.000	25.000
TR80	46.044	4.005	.486	37.000	57.000	20.000
TR75	51.897	4.125	.500	42.000	62.000	20.000
TR67	59.382	3.408	.413	50.000	66.000	16.000
TR60	62.000	3.355	.407	54.000	69.000	15.000
TR50	61.618	3.587	.435	52.000	70.000	18.000
TR40	57.338	3.784	.459	41.000	66.000	25.000
TR33	53.662	4.006	.486	40.000	63.000	23.000
TR25	51.162	3.760	.456	33.000	60.000	27.000
TR20	47.500	3.326	.403	39.000	57.000	18.000
TR10	30.000	6.248	.758	1.000	42.000	41.000

Console right handed subjects (n=49) right brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CR90	32.551	4.184	.598	24.000	44.000	20.000
CR80	48.735	3.569	.510	42.000	57.000	15.000
CR75	54.531	3.422	.489	48.000	64.000	16.000
CR67	60.878	3.756	.537	50.000	70.000	20.000
CR60	63.367	3.689	.527	52.000	73.000	21.000
CR50	62.673	3.092	.442	57.000	69.000	12.000
CR40	58.571	2.979	.426	52.000	65.000	13.000
CR33	55.143	3.202	.457	48.000	62.000	14.000
CR25	52.408	2.645	.378	47.000	57.000	10.000
CR20	48.837	3.596	.514	42.000	61.000	19.000
CR10	33.939	6.210	.887	1.000	41.000	40.000

(table continued)

Table E1 (continued)

Trace right-handed with left-handed relatives (n=24) right brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TR90	28.583	4.995	1.020	16.000	40.000	24.000
TR80	46.208	3.401	.694	38.000	50.000	12.000
TR75	52.458	3.623	.740	43.000	60.000	17.000
TR67	59.750	3.220	.657	50.000	67.000	17.000
TR60	62.708	3.303	.674	53.000	69.000	16.000
TR50	62.208	3.683	.752	54.000	68.000	14.000
TR40	57.750	4.024	.821	48.000	65.000	17.000
TR33	54.542	4.222	.862	44.000	64.000	20.000
TR25	51.875	3.555	.726	45.000	59.000	14.000
TR20	48.000	3.639	.743	42.000	54.000	12.000
TR10	32.000	4.841	.988	24.000	41.000	17.000

Console right-handed with/left-handed relatives (n=14) right brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CR90	32.357	3.388	.905	27.000	39.000	12.000
CR80	48.071	2.759	.737	44.000	55.000	11.000
CR75	54.357	2.790	.746	50.000	61.000	11.000
CR67	61.857	2.742	.733	57.000	67.000	10.000
CR60	64.214	2.577	.689	61.000	69.000	8.000
CR50	63.143	3.570	.954	57.000	69.000	12.000
CR40	58.929	3.222	.861	54.000	65.000	11.000
CR33	55.643	4.448	1.189	48.000	66.000	18.000
CR25	52.714	3.148	.841	48.000	60.000	12.000
CR20	49.143	2.958	.790	45.000	55.000	10.000
CR10	36.357	2.620	.700	33.000	41.000	8.000

(table continued)

Table E1 (continued)

Trace left handed subjects (n=16) right side brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TR90	29.938	3.838	.959	22.000	36.000	14.000
TR80	48.813	3.371	.843	44.000	54.000	10.000
TR75	55.250	3.751	.938	50.000	62.000	12.000
TR67	61.688	3.610	.902	57.000	68.000	11.000
TR60	64.563	3.915	.979	58.000	71.000	13.000
TR50	63.563	3.687	.922	56.000	69.000	13.000
TR40	59.125	3.364	.841	54.000	64.000	10.000
TR33	54.688	3.877	.969	46.000	60.000	14.000
TR25	52.188	3.430	.857	45.000	57.000	12.000
TR20	47.875	3.594	.898	42.000	54.000	12.000
TR10	31.313	5.952	1.488	23.000	40.000	17.000

Console left handed subjects (n=6) right brain widths at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CR90	36.333	4.885	1.994	32.000	43.000	11.000
CR80	50.000	4.733	1.932	45.000	57.000	12.000
CR75	55.833	5.707	2.230	49.000	64.000	15.000
CR67	61.167	3.869	1.579	57.000	66.000	9.000
CR60	63.833	3.371	1.376	60.000	68.000	8.000
CR50	62.667	1.633	.667	61.000	65.000	4.000
CR40	59.000	2.530	1.033	56.000	62.000	6.000
CR33	55.167	1.941	.792	53.000	58.000	5.000
CR25	52.167	1.472	.601	51.000	55.000	4.000
CR20	49.333	1.862	.760	47.000	52.000	5.000
CR10	34.500	2.881	1.176	30.000	37.000	7.000

(table continued)

Table E1 (continued)

Trace subjects (n=108) left-right differences measures at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TD90	2.532	6.097	.584	-12.000	22.000	34.000
TD80	1.954	4.589	.440	-13.000	11.000	24.000
TD75	2.018	4.515	.432	-10.000	14.000	24.000
TD67	.294	3.578	.343	-16.000	8.000	24.000
TD60	-.358	3.324	.318	-16.000	8.000	24.000
TD50	-.872	2.938	.281	-8.000	8.000	16.000
TD40	-.541	2.876	.275	-7.000	15.000	22.000
TD33	-.028	3.510	.336	-8.000	14.000	22.000
TD25	-1.055	4.057	.389	-15.000	25.000	40.000
TD20	-1.257	3.811	.365	-17.000	14.000	31.000
TD10	-1.569	5.731	.549	-28.000	9.000	37.000

Console subjects (n=69) left-right difference measures at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CD90	2.014	4.800	.578	-10.000	11.000	21.000
CD80	2.043	3.935	.474	-7.000	10.000	17.000
CD75	1.406	3.627	.437	-6.000	11.000	17.000
CD67	.029	2.572	.310	-6.000	8.000	14.000
CD60	-.449	2.447	.295	-7.000	5.000	12.000
CD50	-.942	2.093	.252	-6.000	6.000	12.000
CD40	-1.000	2.635	.317	-7.000	5.000	12.000
CD33	-1.043	2.391	.288	-8.000	3.000	11.000
CD25	-1.406	2.232	.269	-7.000	5.000	12.000
CD20	-1.870	2.332	.281	-6.000	5.000	11.000
CD10	-2.812	3.453	.416	-13.000	4.000	17.000

(table continued)

Table E1 (continued)

Trace right handed subjects (n=68) left-right difference measures at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TD90	2.868	5.712	.693	-11.000	16.000	27.000
TD80	2.471	4.615	.560	-13.000	11.000	24.000
TD75	2.721	4.488	.544	-8.000	14.000	22.000
TD67	.838	3.704	.449	-16.000	8.000	24.000
TD60	.235	3.503	.425	-16.000	8.000	24.000
TD50	-.485	2.945	.357	-7.000	8.000	15.000
TD40	-.235	3.120	.378	-6.000	15.000	21.000
TD33	.294	3.726	.452	-7.000	14.000	21.000
TD25	-.779	4.488	.544	-15.000	25.000	40.000
TD20	-1.235	4.122	.500	-17.000	14.000	31.000
TD10	-1.618	5.334	.647	-20.000	9.000	29.000

Console right-handed subjects (n=49) left-right difference measures at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CD90	1.367	4.773	.682	-10.000	11.000	21.000
CD80	1.388	3.779	.540	-7.000	9.000	16.000
CD75	.898	3.601	.514	-6.000	11.000	17.000
CD67	.061	2.824	.403	-6.000	8.000	14.000
CD60	-.388	2.629	.376	-7.000	5.000	12.000
CD50	-.714	2.021	.289	-6.000	6.000	12.000
CD40	-.796	2.638	.377	-7.000	5.000	12.000
CD33	-.735	2.307	.330	-6.000	3.000	9.000
CD25	-1.429	2.318	.331	-7.000	5.000	12.000
CD20	-1.653	2.359	.337	-6.000	5.000	11.000
CD10	-2.816	3.557	.508	-13.000	4.000	17.000

(table continued)

Table E1 (continued)

Trace right-handed with left-handed relatives (n=24) left-right difference measures at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TD90	2.458	6.093	1.244	-4.000	22.000	26.000
TD80	2.125	4.317	.881	-7.000	9.000	16.000
TD75	2.083	4.096	.836	-5.000	10.000	15.000
TD67	.250	3.082	.629	-5.000	6.000	11.000
TD60	-.625	2.516	.514	-6.000	3.000	9.000
TD50	-1.542	2.718	.555	-6.000	2.000	8.000
TD40	-1.292	2.629	.537	-7.000	4.000	11.000
TD33	-.625	3.474	.709	-8.000	9.000	17.000
TD25	-1.708	3.665	.748	-12.000	9.000	16.000
TD20	-1.458	3.270	.668	-8.000	4.000	12.000
TD10	-1.375	4.897	1.000	-13.000	6.000	19.000

Console right-handed with left-handed relatives (n=24) left-right difference measures at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CD90	5.071	3.293	.880	-2.000	10.000	12.000
CD80	5.143	3.325	.889	-1.000	10.000	11.000
CD75	3.571	3.031	.810	-1.000	8.000	9.000
CD67	.214	1.847	.494	-4.000	2.000	6.000
CD60	.000	1.922	.514	-4.000	3.000	7.000
CD50	-1.429	2.533	.677	-6.000	4.000	10.000
CD40	-1.786	2.940	.786	-6.000	5.000	11.000
CD33	-2.071	2.702	.722	-8.000	2.000	10.000
CD25	-1.643	2.205	.589	-6.000	1.000	7.000
CD20	-2.714	2.234	.597	-6.000	1.000	7.000
CD10	-4.000	3.162	.845	-9.000	2.000	11.000

(table continued)

Table E1 (continued)

Trace left-handed subjects (n=16) left-right difference measures at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
TD90	.750	7.576	1.894	-12.000	15.000	27.000
TD80	-.750	4.219	1.055	-8.000	8.000	16.000
TD75	-1.250	4.107	1.027	-10.000	6.000	16.000
TD67	-2.063	2.977	.744	-8.000	3.000	11.000
TD60	-2.500	2.898	.725	-10.000	2.000	12.000
TD50	-1.500	3.204	.801	-8.000	4.000	12.000
TD40	-.750	2.017	.504	-6.000	3.000	9.000
TD33	-.375	2.604	.651	-5.000	3.000	8.000
TD25	-1.188	2.613	.653	-6.000	3.000	9.000
TD20	-1.125	3.481	.870	-11.000	4.000	15.000
TD10	-1.688	8.514	2.129	-28.000	6.000	34.000

Console left-handed subjects (n=6) left-right difference measures at the percentage points

Variable Name	Mean	SD	SE	Min.	Max	Range
CD90	.167	5.672	2.315	-7.000	7.000	14.000
CD80	.167	3.061	1.249	-4.000	4.000	8.000
CD75	.500	3.728	1.522	-4.000	7.000	11.000
CD67	-.667	1.966	.803	-3.000	2.000	5.000
CD60	-2.000	1.414	.577	-4.000	.000	4.000
CD50	-1.667	1.366	.558	-3.000	.000	3.000
CD40	-.833	1.172	.703	-3.000	2.000	5.000
CD33	-1.167	1.941	.792	-3.000	2.000	5.000
CD25	-.667	1.633	.667	-3.000	1.000	4.000
CD20	-1.667	2.251	.919	-4.000	2.000	6.000
CD10	.000	1.095	.447	-1.000	2.000	3.000

Table E2

Analysis of Variance F Values and Associated Significance of CT Trace Measures

Dependent cariable/ Handedness category	Mean	SD	ANOVA F	Sig. (p=) Sig. pairs
Left Oc. 1 (90% of AP)			.5215	.5952
Rh	29.838	4.609		
Rhl	31.042	4.814		none
Lh	30.687	8.260		
Left Oc. 2 (80% of AP)			.1024	.9028
Rh	48.515	3.513		
Rhl	48.333	4.167		none
Lh	48.062	3.820		
Left Oc. 3 (75% of AP)			.1665	.8468
Rh	54.617	3.844		
Rhl	54.542	4.107		none
Lh	54.000	3.559		
Left Oc. 4 (67% of AP)			.1995	.8194
Rh	60.221	3.656		
Rhl	60.000	3.162		none
Lh	59.625	3.052		
Left T-P 2 (60% of AP)			.0257	.9746
Rh	62.235	3.738		
Rhl	62.083	3.229		none
Lh	62.062	3.214		
Left T-P 3 (50% of AP)			.9406	.3937
Rh	61.132	3.162		
Rhl	60.667	3.226		none
Lh	62.062	3.129		

(table continued)

Table E2 (continues)

Analysis of Variance F Values and Associated Significance of CT Trace Measures

			ANOVA	
Dependent variable/ Handedness category	Mean	SD	*F*	Sig. (p=) Sig. pairs
Left T-P 4 (40% of AP)			1.5778	.2113
Rh	57.102	3.177		
Rhl	56.458	3.822		none
Lh	58.375	3.403		
Left Fr. 1 (33% of AP)			.0605	.9414
Rh	53.956	3.526		
Rhl	53.951	4.951		none
Lh	54.312	3.888		
Left Fr. 2 (25% of AP)			.2906	.7484
Rh	50.382	3.574		
Rhl	50.167	3.130		none
Lh	51.000	3.521		
Left Fr. 3 (20% of AP)			.2033	.8164
Rh	46.265	3.281		
Rhl	46.667	3.996		none
Lh	46.750	3.276		
Left Fr. 4 (10% of AP)			.8243	.4414
Rh	29.015	7.719		
Rhl	31.333	5.378		none
Lh	29.625	9.715		

(table continued)

Table E2 (continues)

Analysis of Variance F Values and Associated Significance of CT Trace Measures

Dependent variable/ Handedness category	Mean	SD	ANOVA F	Sig.(p=) Sig. pairs
Right Oc. 1 (90% of AP)			2.6924	.0724
Rh	26.970	5.223		
Rhl	28.583	4.995		none
Lh	29.937	3.838		
Right Oc. 2 (80% of AP)			3.5339	.0327
Rh	46.044	4.005		
Rhl	46.208	3.401	Sig. diff 1 & 3,	
Lh	48.813	3.371		2 & 3
Right Oc. 3 (75% of AP)			4.6276	.0119
Rh	51.897	4.125		
Rhl	52.458	3.623	Sig. diff 1 & 3	
Lh	55.250	3.751		2 & 3
Right Oc. 4 (67% of AP)			2.9854	.0548
Rh	59.382	3.408		
Rhl	59.750	3.220		none
Lh	61.687	3.609		
Right T-P 2 (60% of AP)			3.6543	.0292
Rh	62.000	3.355		
Rhl	62.708	3.303	Sig. diff. 1 & 3	
Lh	64.562	3.915		
Right T-P 3 (50% of AP)			1.9011	.1545
Rh	61.617	3.587		
Rhl	62.208	3.683		none
Lh	62.037	3.687		

(table continued)

Table E2 (continues)

Analysis of Variance F Values and Associated Significance of CT Trace Measures

			ANOVA	
Dependent variable/ Handedness category	Mean	SD	*F*	Sig. (p=) Sig. pairs
Right T-P 4 (40% of AP)			1.4492	.2394
Rh	57.338	3.784		
Rhl	57.750	4.024		none
Lh	59.125	3.364		
Right Fr. 1 (33% of AP)			.6867	.5055
Rh	53.662	4.006		
Rhl	54.542	4.222		none
Lh	54.687	3.877		
Right Fr. 2 (25% of AP)			.6917	.5030
Rh	51.162	3.760		
Rhl	51.875	3.555		none
Lh	52.187	3.429		
Right Fr. 3 (20% of AP)			.3195	.7272
Rh	47.500	3.325		
Rhl	48.125	3.639		none
Lh	47.875	3.594		
Right Fr. 4 (10% of AP)			1.0926	.3391
Rh	30.632	6.248		
Rhl	32.708	4.841		none
Lh	31.312	5.952		

(table continued)

Table E2 (continues)

Analysis of Variance F Values and Associated Significance of CT Trace Measures

Dependent variable/ Handedness category	Mean	SD	ANOVA F	Sig. (p=) Sig. pairs
L÷R Oc. 1 (90% of AP)			1.2358	.2948
Rh	1.137	.234		
Rhl	1.121	.316		none
Lh	1.024	.285		
L÷R Oc. 2 (80% of AP)			3.5934	.0309
Rh	1.059	.099		
Rhl	1.049	.096	Sig. diff	1 & 3
Lh	.987	.087		
L÷R Oc. 3 (75% of AP)			5.2024	.0070
Rh	1.057	.089		
Rhl	1.042	.081	Sig. diff	1 & 3
Lh	.980	.074		2 & 3
L÷R Oc. 4 (67% of AP)			4.3724	.0150
Rh	1.016	.062		
Rhl	1.006	.052	Sig. diff	1 & 3
Lh	.988	.046		2 & 3
L÷R T-P 2 (60% of AP)			4.578	.0124
Rh	1.005	.056		
Rhl	.991	.039	Sig. diff	1 & 3
Lh	.963	.042		
L÷R T-P 3 (50% of AP)			1.5431	.2185
Rh	.994	.048		
Rhl	.976	.043		none
Lh	.978	.049		

(table continued)

Table E2 (continues)

Analysis of Variance F Values and Associated Significance of CT Trace Measures

Dependent Variable/ Handedness Category	Mean	SD	ANOVA F	Sig. (p=) Sig. pairs
L÷R T-P 4 (40% of AP)			1.1683	.3149
Rh	.998	.062		
Rhl	.979	.045		none
Lh	.988	.033		
L÷R Fr. 1 (33% of AP)			.8173	.4444
Rh	1.009	.076		
Rhl	.989	.064		none
Lh	.994	.047		
L÷R Fr. 2 (25% of AP)			.4240	.6555
Rh	.990	.113		
Rhl	.969	.066		none
Lh	.978	.048		
L÷R Fr. 3 (20% of AP)			.0673	.9349
Rh	.977	.087		
Rhl	.971	.066		none
Lh	.979	.068		
L÷R Fr. 4 (10% of AP)			.0650	.9371
Rh	.948	.194		
Rhl	.966	.148		none
Lh	.952	.292		

(table continued)

Table E2 (continues)

Analysis of Variance F Values and Associated Significance of CT Trace Measures

			ANOVA	
Dependent variable/ Handedness category	Mean	SD	F	Sig. (p=) Sig. pairs
L-R Oc. 1 (90% of AP)			.7818	.4602
Rh	2.867	5.712		
Rhl	2.458	6.093		none
Lh	.750	7.576		
L-R Oc. 2 (80% of AP)			3.3560	.0387
Rh	2.471	4.615		
Rhl	2.125	4.317	Sig. diff 1 & 3	
Lh	-0.750	4.219		
L-R Oc. 3 (75% of AP)			5.3982	.0059
Rh	2.721	4.488		
Rhl	2.083	4.096	Sig. diff 1 & 3	
Lh	-1.250	4.107	2 & 3	
L-R Oc. 4 (67% of AP)			4.5039	.0133
Rh	.838	3.704		
Rhl	.250	3.082	Sig. diff 1 & 3	
Lh	-2.063	2.977	2 & 3	
L-R T-P 2 (60% of AP)			4.7542	.0106
Rh	.235	3.503		
Rhl	-0.625	2.516	Sig. diff 1 & 3	
Lh	-2.500	2.898		
L-R T-P 3 (50% of AP)			1.5804	.2107
Rh	-0.4853	2.945		
Rhl	-1.542	2.718		none
Lh	-1.500	3.204		

(table continued)

Table E2 (continues)

Analysis of Variance F Values and Associated Significance of CT Trace Measures

Dependent variable/ Handedness category	Mean	SD	ANOVA F	Sig. (p=) Sig. pairs
L-R T-P 4 (40% of AP)			1.2385	.2940
Rh	-0.235	3.120		
Rhl	-1.292	2.628		none
Lh	-0.750	2.017		
L-R Fr. 1 (33% of AP)			.7015	.4981
Rh	0.294	3.726		
Rhl	-0.625	3.474		none
Lh	-0.375	2.604		
L-R Fr. 2 (25% of AP)			.4675	.6279
Rh	-0.779	4.488		
Rhl	-1.708	3.665		none
Lh	-1.187	2.613		
L-R Fr. 3 (20% of AP)			.0426	.9584
Rh	-1.235	4.122		
Rhl	-1.458	3.270		none
Lh	-1.125	3.481		
L-R Fr. 4 (10% of AP)			.0190	.9811
Rh	-1.618	5.334		
Rhl	-1.375	4.897		none
Lh	-1.687	8.514		

Table E3

Analysis of Variance F Values and Associated Significance of Console CT Measures

Dependent variable/ Handedness category	Mean	SD	ANOVA F	Sig. (p=) / Sig. pairs
Left Oc. 1 (90% of AP)			5.4705	.0063
Rh	33.918	3.741		
Rhl	37.428	2.409	Sig. diff 1 & 2	
Lh	36.500	5.822		
Left Oc. 2 (80% of AP)			4.5436	.0142
Rh	50.122	3.539		
Rhl	53.214	3.118	Sig. diff 1 & 2	
Lh	50.167	2.994		
Left Oc. 3 (75% of AP)			2.4431	.0947
Rh	55.428	3.910		
Rhl	57.928	3.385		none
Lh	56.333	3.011		
Left Oc. 4 (67% of AP)			.6413	.5299
Rh	60.939	3.869		
Rhl	62.071	2.814		none
Lh	60.500	2.510		
Left T-P 2 (60% of AP)			1.1579	.3204
Rh	62.979	3.677		
Rhl	64.214	2.966		none
Lh	61.833	2.228		
Left T-P 3 (50% of AP)			.2629	.7696
Rh	61.959	3.048		
Rhl	61.714	3.496		none
Lh	61.000	2.828		

(table continued)

Table E3 (continues)

Analysis of Variance F Values and Associated Significance of Console CT Measures

Dependent variable/ Handedness category	Mean	SD	ANOVA F	Sig. (p=) Sig. pairs
Left T-P 4 (40% of AP)			.3232	.7249
Rh	57.775	3.043		
Rhl	57.143	3.394		none
Lh	58.167	1.329		
Left Fr. 1 (33% of AP)			.3582	.7003
Rh	54.408	3.214		
Rhl	53.571	3.995		none
Lh	54.000	2.191		
Left Fr. 2 (25% of AP)			.0947	.9098
Rh	50.979	2.912		
Rhl	51.071	2.368		none
Lh	51.500	2.429		
Left Fr. 3 (20% of AP)			.5211	.5963
Rh	47.184	2.948		
Rhl	46.428	2.593		none
Lh	47.667	2.658		
Left Fr. 4 (10% of AP)			1.0489	.3561
Rh	31.122	6.412		
Rhl	32.357	3.692		none
Lh	34.500	2.510		

(table continued)

Table E3 (continues)

Analysis of Variance F Values and Associated Significance of CT Console Measures

			ANOVA	
Dependent variable/ Handedness category	Mean	SD	F	Sig. (p=) Sig. pairs
Right Oc. 1 (90% of AP)			2.3984	.0987
Rh	32.551	4.184		
Rhl	32.357	3.388		none
Lh	36.333	4.885		
Right Oc. 2 (80% of AP)			.6309	.5353
Rh	48.735	3.569		
Rhl	48.071	2.758		none
Lh	50.000	4.733		
Right Oc. 3 (75% of AP)			.4067	.6675
Rh	54.531	3.422		
Rhl	54.357	2.790		none
Lh	55.833	5.707		
Right Oc. 4 (67% of AP)			.4068	.6674
Rh	60.877	3.756		
Rhl	61.857	2.742		none
Lh	61.167	3.869		
Right T-P 2 (60% of AP)			.3411	.7122
Rh	63.367	3.689		
Rhl	64.214	2.577		none
Lh	63.579	3.371		
Right T-P 3 (50% of AP)			.1276	.8804
Rh	62.673	3.091		
Rhl	63.143	3.570		none
Lh	62.667	1.633		

(table continued)

Table E3 (continues)

Analysis of Variance F Values and Associated Significance of Console CT Measures

Dependent variable/ Handedness category	Mean	SD	ANOVA F	Sig.(p=) Sig. pairs
Right T-P 4 (40% of AP)			.1145	.8920
Rh	58.571	2.979		
Rhl	58.929	3.222		none
Lh	59.000	2.529		
Right Fr. 1 (33% of AP)			.1188	.8882
Rh	55.143	3.202		
Rhl	55.643	4.448		none
Lh	55.167	1.941		
Right Fr. 2 (25% of AP)			.1072	.8985
Rh	52.408	2.645		
Rhl	52.714	3.148		none
Lh	52.167	1.147		
Right Fr. 3 (20% of AP)			.0890	.9150
Rh	48.837	3.596		
Rhl	49.143	2.957		none
Lh	49.333	1.862		
Right Fr. 4 (10% of AP)			1.0606	.3521
Rh	33.939	6.209		
Rhl	36.357	2.619		none
Lh	34.500	2.881		

(table continued)

Table E3 (continues)

Analysis of Variance F Values and Associated Significance of CT Console Measures

Dependent variable/ Handedness category	Mean	SD	ANOVA F	Sig. (p=) Sig. pairs
L÷R Oc. Ratio 1 (90% of AP)			3.7070	.0298
Rh	1.0548	.153		
Rhl	1.1654	.111	Sig. diff 2 & 3,	
Lh	1.0109	.159		2 & 1
L÷R Oc. Ratio 2 (80% of AP)			6.5913	.0025
Rh	1.0315	.078		
Rhl	1.1090	.072	Sig. diff 2 & 3,	
Lh	1.0070	.059		2 & 1
L÷R Oc. Ratio 3 (75% of AP)			3.0740	.0529
Rh	1.0181	.068		
Rhl	1.0667	.059		none
Lh	1.0140	.071		
L÷R Oc. Ratio 4 (67% of AP)			.2192	.8038
Rh	1.0019	.047		
Rhl	1.0038	.029		none
Lh	.9905	.032		
L÷R T-P. Ratio 2 (60% of AP)			1.4432	.2435
Rh	.9946	.041		
Rhl	1.0002	.031		none
Lh	.9694	.021		
L÷R T-P. Ratio 3 (50% of AP)			1.0634	.3511
Rh	.9891	.033		
Rhl	.9781	.039		none
Lh	.9730	.022		

(table continued)

Table E3 (continues)

Analysis of Variance F Values and Associated Significance of Console CT Measures

Dependent variable/ Handedness category	Mean	SD	ANOVA F	Sig. (p=) Sig. pairs
L÷R T-P. Ratio 4 (40% of AP)			.7636	.4701
Rh	.9873	.045		
Rhl	.9706	.050		none
Lh	.9868	.029		
L÷R FR. Ratio 1 (33% of AP)			1.6977	.1910
Rh	.9875	.042		
Rhl	.9641	.046		none
Lh	.9792	.036		
L÷R FR. Ratio 2 (25% of AP)			.3502	.7058
Rh	.9734	.044		
Rhl	.9702	.039		none
Lh	.9871	.032		
L÷R FR. Ratio 3 (20% of AP)			1.1839	.3125
Rh	.9680	.049		
Rhl	.9459	.044		none
Lh	.9664	.047		
L÷R FR. Ratio 4 (10% of AP)			2.8997	.0621
Rh	.9203	.100		
Rhl	.8906	.087		none
Lh	1.0012	.033		

(table continued)

Table E3 (continues)

Analysis of Variance F Values and Associated Significance of Console CT Measures

Dependent variable/ Handedness category	Mean	SD	ANOVA F	Sig. (p=) Sig. pairs
L-R Dif. Oc. 1 (90% of AP)			4.0645	.0216
Rh	1.3673	4.773		
Rhl	5.0714	3.293	Sig. diff 2 & 3,	
Lh	.1667	5.672		2 & 1
L-R Dif. Oc. 2 (80% of AP)			6.6547	.0023
Rh	1.3878	3.388		
Rhl	5.1429	3.325	Sig. diff 2 & 3,	
Lh	.1667	3.061		2 & 1
L-R Dif. Oc. 3 (75% of AP)			3.3845	.0399
Rh	.8980	3.601		
Rhl	3.5714	3.031	Sig. diff 2 & 1	
Lh	.5000	3.728		
L-R Dif. Oc. 4 (67% of AP)			.2539	.7765
Rh	.0612	2.824		
Rhl	.2143	1.847		none
Lh	-.6667	1.966		
L-R Dif. T-P 2 (60% of AP)			1.4771	.2358
Rh	-.3878	2.628		
Rhl	.0000	1.922		none
Lh	-2.0000	1.414		
L-R Dif. T-P 3 (50% of AP)			1.0292	.3629
Rh	-.7143	2.021		
Rhl	-1.4286	2.533		none
Lh	-1.6667	1.366		

(table continued)

Table E3 (continues)

Analysis of Variance F Values and Associated Significance of Console CT Measures

Dependent variable/ Handedness category	Mean	SD	ANOVA F	ANOVA Sig. (p=) Sig. pairs
L-R Dif. T-P 4 (40% of AP)			.7765	.4642
Rh	-.7959	2.638		
Rhl	-1.7857	2.939		none
Lh	-.8333	1.722		
L-R Dif. Fr 1 (33% of AP)			1.7475	.1822
Rh	-.7347	2.307		
Rhl	-2.0714	2.702		none
Lh	-1.1667	1.941		
L-R Dif. Fr 2 (25% of AP)			.4034	.6696
Rh	-1.4286	2.318		
Rhl	-1.6429	2.205		none
Lh	-.6667	1.633		
L-R Dif. Fr 3 (20% of AP)			1.1576	.3205
Rh	-1.6531	2.359		
Rhl	-2.7143	2.234		none
Lh	-1.6667	2.251		
L-R Dif. Fr 4 (10% of AP)			2.9834	.0575
Rh	-2.8163	3.557		
Rhl	-4.0000	3.162		none
Lh	.0000	1.095		

Table E4

Chi-Square Frequencies of Asymmetry in the

Handedness Groups (Trace)

Measurement point: 90%			
# of cases per cell		Handedness Category	
Column %	Rh	Rhl	Lh
Left side greater	42 **61.8**	12 **50.0**	7 **43.8**
Right side greater	12 **17.6**	7 **29.2**	5 **31.3**
Both sides equal	14 **20.6**	5 **20.8**	4 **25.0**
Chi χ^2 value	degrees of freedom	significance (p=)	
2.84337	4	.58437	

Measurement point: 80%			
Left side greater	43 **63.2**	14 **58.3**	6 **37.5**
Right side greater	10 **14.7**	6 **25.0**	6 **37.5**
Both sides equal	15 **22.1**	4 **16.7**	4 **25.0**
Chi χ^2 value	degrees of freedom	significance (p=)	
5.46210	4	.24308	

Measurement point: 75%			
Left side greater	42 **61.8**	13 **54.2**	4 **25.0**
Right side greater	8 **11.8**	5 **20.8**	8 **50.0**
Both sides equal	18 **26.5**	6 **25.0**	4 **25.0**
Chi χ^2 value	degrees of freedom	significance (p=)	
12.99580	4	.01130	

(table continues)

Table E4 (continued)

Chi-square Frequencies of Asymmetry in the Handedness Groups (Trace)

Measurement point: 67%

Left side greater	31 **45.6**	10 **41.7**	2 **12.5**
Right side greater	13 **19.1**	8 **33.3**	10 **62.5**
Both sides equal	24 **35.3**	6 **25.0**	4 **25.0**

Chi χ^2 value	degrees of freedom	significance (p=)
13.15895	4	.01052

Measurement point: 60%

Left side greater	26 **38.2**	6 **25.0**	1 **6.3**
Right side greater	15 **22.1**	8 **33.3**	9 **56.3**
Both sides equal	27 **39.7**	10 **41.7**	6 **37.5**

Chi χ^2 value	degrees of freedom	significance (p=)
9.94402	4	.04138

Measurement point: 50%

Left side greater	15 **22.1**	4 **16.7**	3 **18.8**
Right side greater	27 **39.7**	10 **41.7**	8 **50.0**
Both sides equal	26 **38.2**	10 **41.7**	5 **31.3**

Chi χ^2 value	degrees of freedom	significance (p=)
0.88480	4	.92673

(table continues)

Table E4 (continued)

Chi-square Frequencies of Asymmetry in the

Handedness Groups (Trace)

Measurement point: 40%

# of cases per cell	Handedness Category		
Column %	Rh	Rhl	Lh
Left side greater	15 **22.1**	2 **20.8**	2 **12.5**
Right side greater	24 **35.3**	10 **41.7**	4 **25.0**
Both sides equal	29 **42.6**	12 **50.0**	10 **62.5**

Chi χ^2 value	degrees of freedom	significance (p=)
4.06647	4	.39708

Measurement point: 33%

Left side greater	25 **36.8**	5 **20.8**	5 **31.3**
Right side greater	22 **32.4**	8 **33.3**	7 **37.5**
Both sides equal	21 **30.9**	11 **45.8**	5 **31.3**

Chi χ^2 value	degrees of freedom	significance (p=)
2.70707	4	.60798

Measurement point: 25%

Left side greater	11 **16.2**	4 **16.7**	2 **12.5**
Right side greater	28 **41.2**	12 **50.0**	6 **37.5**
Both sides equal	29 **42.6**	8 **33.3**	8 **50.0**

Chi χ^2 value	degrees of freedom	significance (p=)
1.24900	4	.86997

(table continues)

Table E4 (continued)

Chi-square Frequencies of Asymmetry in the

Handedness Groups (Trace)

Measurement point: 20%

# of cases per cell	Handedness Category		
Column %	Rh	Rhl	Lh
Left side greater	15 **22.1**	6 **25.0**	3 **18.8**
Right side greater	34 **50.0**	12 **50.0**	5 **31.3**
Both sides equal	19 **27.9**	6 **25.0**	8 **50.0**

Chi χ^2 value	degrees of freedom	significance (p=)
3.55999	4	.46882

Measurement point: 10%

Left side greater	17 **25.0**	7 **29.2**	8 **50.0**
Right side greater	33 **48.5**	9 **37.5**	7 **43.8**
Both sides equal	18 **26.5**	8 **33.3**	1 **6.3**

Chi χ^2 value	degrees of freedom	significance (p=)
6.19636	4	.18496

Table E5

Chi-square Frequencies of Asymmetry in the Handedness Groups (Console)

Measurement point: 90%

# of cases per cell	Handedness Category		
Column %	Rh	Rhl	Lh
Left side greater	27 **55.1**	12 **85.7**	2 **66.8**
Right side greater	14 **28.6**	1 **7.1**	2 **33.3**
Both sides equal	8 **16.3**	1 **7.1**	2 **33.3**

Chi χ^2 value	degrees of freedom	significance (p=)
6.52380	4	.16330

Measurement point: 80%

Left side greater	26 **53.1**	11 **78.6**	2 **33.3**
Right side greater	11 **22.4**	0 **0.0**	2 **33.3**
Both sides equal	12 **24.5**	3 **21.4**	2 **33.3**

Chi χ^2 value	degrees of freedom	significance (p=)
5.76717	4	.21722

Measurement point: 75%

Left side greater	23 **46.9**	9 **64.3**	1 **16.7**
Right side greater	15 **30.6**	0 **0.0**	2 **33.3**
Both sides equal	11 **22.4**	5 **35.7**	3 **50.0**

Chi χ^2 value	degrees of freedom	significance (p=)
8.26262	4	.08242

(table continues)

Table E5 (continued)

Chi-square Frequencies of Asymmetry in the Handedness Groups (Console)

Measurement point: 67%

# of cases per cell	Handedness Category		
Column %	Rh	Rhl	Lh
Left side greater	14 **28.6**	4 **28.6**	1 **16.7**
Right side greater	14 **28.6**	2 **14.3**	3 **50.0**
Both sides equal	21 **42.9**	8 **57.1**	2 **33.3**

Chi χ^2 value	degrees of freedom	significance (p=)
2.98448	4	.56043

Measurement point: 60%

Left side greater	11 **22.4**	3 **21.4**	0 **0.0**
Right side greater	14 **28.6**	3 **21.4**	4 **66.7**
Both sides equal	24 **49.0**	8 **57.1**	2 **33.3**

Chi χ^2 value	degrees of freedom	significance (p=)
4.84212	4	.30388

Measurement point: 50%

Left side greater	5 **10.2**	2 **14.3**	0 **0.0**
Right side greater	18 **36.7**	8 **57.1**	4 **5.8**
Both sides equal	26 **53.1**	4 **28.6**	2 **33.3**

Chi χ^2 value	degrees of freedom	significance (p=)
4.35050	4	.36064

(table continues)

Table E5 (continued)

Chi-square Frequencies of Asymmetry in the

Handedness Groups (Console)

Measurement point: 40%

# of cases per cell	Handedness Category		
Column %	Rh	Rhl	Lh
Left side greater	4 **14.3**	1 **7.1**	1 **16.7**
Right side greater	16 **32.7**	7 **50.0**	2 **33.3**
Both sides equal	26 **53.1**	6 **42.9**	3 **50.0**
Chi χ^2 value	degrees of freedom	significance (p=)	
1.63585	4	.80233	

Measurement point: 33%

Left side greater	9 **18.4**	1 **7.1**	1 **16.7**
Right side greater	21 **42.9**	1 **57.1**	3 **50.0**
Both sides equal	19 **38.8**	5 **35.7**	2 **33.3**
Chi χ^2 value	degrees of freedom	significance (p=)	
1.42052	4	.84062	

Measurement point: 25%

Left side greater	5 **10.2**	0 **0.0**	0 **0.0**
Right side greater	21 **42.9**	6 **42.9**	2 **33.3**
Both sides equal	23 **46.9**	8 **57.1**	4 **66.7**
Chi χ^2 value	degrees of freedom	significance (p=)	
2.71181	4	.60715	

(table continues)

Table E5 (continued)

Chi-square Frequencies of Asymmetry in the Handedness Groups (Console)

Measurement point: 20%

* of cases per cell	Handedness Category		
Column %	Rh	Rhl	Lh
Left side greater	4 **8.2**	0 **0.0**	1 **16.7**
Right side greater	28 **57.1**	9 **64.3**	4 **66.7**
Both sides equal	17 **34.7**	5 **35.7**	1 **16.7**

Chi χ^2 value	degrees of freedom	significance (p=)
2.50871	4	.64308

Measurement point: 10%

Left side greater	5 **10.2**	1 **7.1**	1 **16.7**
Right side greater	31 **63.3**	11 **78.6**	0 **0.0**
Both sides equal	13 **26.5**	2 **14.3**	5 **83.3**

Chi χ^2 value	degrees of freedom	significance (p=)
12.05488	4	.01695

VITA

Steven Adam Lifson

Candidate for the Degree of

Doctor of Philosophy

Dissertation: Neuroanatomical Asymmetry, Handedness, And Family History Of Handedness: A Study Of The Markers Of Structural And Functional Lateralization

Major Field: Psychology

Biographical Information:

Personal Data: Born July 25, 1956 in New York City, New York; son of David and Anita R. Lifson.

Education: State University of New York at Albany, BA Psychology (1979); Teachers College, Columbia University, New York, MA and M.Ed. Psychological Counseling and Rehabilitation (1981); Utah State University, Logan, Ph.D. Psychology (1989).

Professional Experience (partial): Psychology Intern, VAMC, Buffalo, New York (1987-1988); Psychological Specialist, Clinical Services Program, DCHP, Utah State University, Logan (1985-1987); Research Assistant, Test Administration and Student Training Project, DCHP, Utah State University, Logan, Utah (1983-1984); Staff Counselor, Social Rehabilitation Program, Postgraduate Center West, New York City (1981-1982); Rehabilitation Counseling Trainee, Social Rehabilitation Program, Postgraduate Center West, New York City (1981); Rehabilitation Counseling Intern, Social Rehabilitation Program, Postgraduate Center West, New York City (1980); Crisis Counselor, Middle Earth Counseling and Crisis Center, State University of NY at Albany (1977-1979).

Publications and Presentations:

Lifson, S. (1989) Neuroanatomical asymmetry, handedness, and family history of handedness: A study of the markers of structural and functional lateralization. Paper presented at the Sigma Xi Student Scientific Research Poster Competition, Logan, Utah April 25.

Lifson, S., & Scruggs, T. E. (1984). Passage independence in reading comprehension items: A follow-up. Perceptual And Motor Skills, 58, 945-946.

Scruggs, T. E., Bennion, K., & Lifson, S. (1985). An analysis of children's strategy use on reading achievement tests. Elementary School Journal, 85, (4).

Scruggs, T. E., Bennion, K., & Lifson, S. (1985). Learning disabled student's spontaneous use of test-taking skills on reading achievement tests. Learning Disability Quarterly, 8(3, Summer) 205-210.

Scruggs, T. E., & Lifson, S. (1985). Are learning disabled students "test-wise"? An inquiry into reading comprehension test items. Paper presented at the annual meeting of the American Educational Research Association, Chicago.

Scruggs, T. E., & Lifson, S. (1985). Current conceptions of test-wiseness: Myths and realities. School Psychology Review, 14, 339-350.